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EDITORIAL NOTE

Beginning with this volume, issues of Philips Technical Review will no longer be indicated by the month. The average size of the issues and the number of issues per year remain unchanged. The actual *date* of publication will appear on the first page of each issue.

AN EMISSION ELECTRON MICROSCOPE FOR RESEARCH AT HIGH TEMPERATURES

by G. BAAS and G. W. RATHENAU *). **537.533.35:621.385.833:620.186**

In the short time of its existence the electron microscope has already rendered inestimable service in many branches of science. Its importance as an aid to research can be judged from the numerous types of electron microscopes that have been developed in recent years. The emission microscope represents the outcome of a rather special line of development pursued at the Philips Research Laboratories in an attempt to apply electron microscopy to certain metallurgical investigations for which normal "transmission microscopes" are unsuitable.

The emission microscope occupies a special place in the history of electron microscopy, for the first electron microscopes were of this type. These early microscopes were electron lenses which produced an image of an electron-emitting metallic surface. Strangely enough, however, the emission microscope has been put to practical use by only a few workers. About 1935 Burgers and Ploos van Amstel investigated nickel-iron, iron, zirconium, etc. with such a microscope, in the Philips' Research Laboratories at Eindhoven [1]). In spite of the low magnification and resolving power of their microscope, they were able to derive valuable information on transformations in metals at high temperatures. Later, Mecklenburg and Kinder [2]) developed emission microscopes for higher magnifications, but as far as we are aware, these were not employed in any systematic research and the development of microscopes of this kind was for a long time at a standstill.

There are perhaps two main reasons why the emission microscope has been neglected by designers of electron-optical instruments since the early days of electron microscopy:

1) From the theoretical investigations of Recknagel, et al., [3]) [4]) it became clear that the resolving power of any practical emission microscope must inevitably be far inferior to that of the "transmission microscope".
2) The transmission microscope has many applications in medicine, biology and other fields, that are virtually closed to the emission microscope.

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[1]) W. G. Burgers and J. J. A. Ploos van Amstel, Philips tech. Rev. **1**, 312-316, 317-320, 1936; Physica **4**, 5-14, 15-22, 1937 and **5**, 304-312, 313-319, 1938; Nature **141**, 330-331, 1938.

[2]) E. Kinder, Naturwiss. **30**, 591-592, 1942. W. Mecklenburg, Z. Physik **120**, 21-30, 1942/43.

[3]) A. Recknagel, Z. Physik **117**, 689-708, 1940/41.

[4]) A. Recknagel, Z. Physik **120**, 331-362, 1942/43. A useful review of the work of Recknagel and others on the emission microscope may be found in the article by H. Mahl; Die elektronenmikroskopische Untersuchung von Oberflächen, Ergebn. exakt. Naturw. **21**, 262-312, 1945.

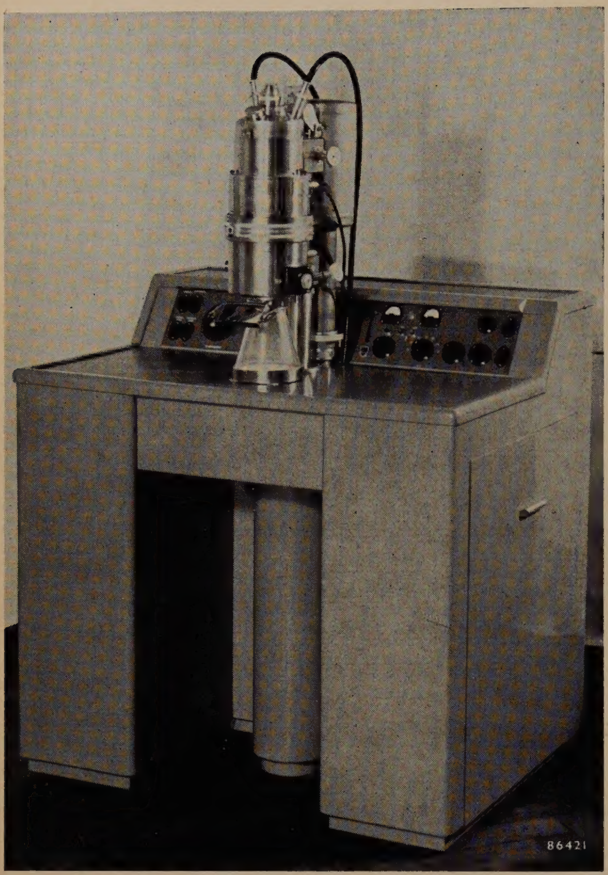

Fig. 1. Emission electron microscope developed by Philips.

We shall examine the first point in more detail later. As to the second point, it is also a fact that there are some fields of investigation where the emission microscope is pre-eminently suited [5]. This is especially true of the investigation of materials at high temperatures, already referred to. In polycrystalline metals, consisting of grains of like or unlike chemical composition, structures can be observed with the emission microscope that are unstable at room temperature. Moreover the grain growth and the transition of a metal into another phase can be observed while in progress, presenting a fascinating spectacle, which once witnessed is never to be forgotten.

After the war, at a time when great advances were being made in metal physics, and high-temperature materials were gaining in practical significance as a result of the development of new engines, plans were drawn up at Philips for an emission microscope for normal laboratory use. Direct impetus was given to this project by research into materials resistant to high temperature in connection with the Philips hot-air engine. The microscope developed in the course of this work will be described in its present form (see *fig. 1*) in this article. The aim of the design was a higher magnification and resolving power than are possible with the optical microscope. The design is based on an emission microscope constructed to the specifications of Le Poole in the Philips Research Laboratories in Eindhoven, in 1947, for investigating oxide cathodes. Experience in the development of transmission microscopes was freely drawn upon, and consequently the microscope now to be described shows considerable similarity to the EM 75 KV transmission microscope, the subject of a recent article in this Review [6]).

Image formation in the emission microscope

In transmission electron microscopes, the object investigated is "illuminated" with a beam of electrons accelerated to a high energy. The electrons which, after passing through the object, carry the information and must be focused to an image, maintain an almost constant energy during the whole process. This is not the case in the emission microscope. Here the information is carried by electrons that have been emitted with very low velocity by the object under investigation, which is itself the cathode, and the focussing to an image must be accompanied by acceleration of the electrons. Hence the first (and sometimes the only) electronic lens in the emission microscope is always an electrostatic "immersion lens": the electrons are accelerated because the object itself lies in the electric field of the electronic lens. The "refractive index" in the space in which the electrons are propagated is therefore greater than 1 at the object. This is also a feature of immersion objectives in the optical microscope.

A direct consequence of the low velocity of emission of the electrons, is that electrons leaving the cathode at wide angles to the optical axis, are nevertheless sufficiently refracted by the field to be able to take part in the production of the image. This is another difference between emission and transmission microscopes, for in the latter, the paths of the electrons leaving the object make only very small angles with the optical axis.

These points of difference explain why, even on theoretical grounds, it is impossible to attain as high a resolving power with the emission microscope as with the transmission microscope. Practical limitations, as we shall see, make the situation still more unfavourable to the emission microscope.

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[5]) See also: M. Gauzit and A. Septier, Bull. micros. Appl. **1**, 109, 1951. R. D. Heidenreich, J. appl. Phys. **26**, 757-766, 879-889, 1955.

[6]) A. C. van Dorsten and J. B. Le Poole, The EM 75 kV, an electron microscope of simplified construction, Philips tech. Rev. **17**, 47-59, 1955/56.

An exhaustive study of the geometrical optics of the emission microscope by Recknagel[3]) has shown that the resolving power is given, to a first approximation, by

$$r = \frac{\varepsilon}{E}. \quad \ldots\ldots\ldots \quad (1)$$

Here E is the strength of the electric field at the cathode surface, and ε the most probably energy (in electron volts) of the electrons emitted by the cathode, which are assumed to have a Maxwellian velocity distribution.

Equation 1 indicates that for a high resolving power, the field strength E should be made as high as possible, and the emission energy ε as low as possible. This is already understandable from physical considerations. Image defects (spherical and chromatic aberration) which limit the resolving power, will be smallest, the closer the electrons keep to the axis — and this requires both a high field strength E and a low initial energy ε.

In practice the field strength E at the cathode is limited by the danger of electrical breakdown, which will be discussed more fully later. In the microscope to be described below, a field strength of 100 kV/cm (or, more exactly, between about 50 and 150 kV/cm) can be used. The mean emission energy ε depends upon the temperature of the cathode. At a temperature of 1000 °C, such as obtains in the investigations under discussion, $\varepsilon \approx 0.1$ eV, so that according to equation (1) the maximum resolving power of this microscope will be 100 Å.

Recknagel has also studied the movement of electrons in the emission microscope from the standpoint of wave-mechanics[4]) and showed to what extent calculation of the resolving power by formula (1), derived from geometrical optics, is justified. Formula (1) is found to be valid, provided a magnitude $\varkappa_0$, which represents, essentially, the ratio of ε/E to the wavelength of the electrons at the cathode, is appreciably greater than 1 (*loc. cit.*, page 352).

According to the temperature of the specimen and the applied high voltage, the value of $\varkappa_0$ in the case in question lies between about 10 and 2.5, so that equation (1) is still applicable.

An important consideration in designing the present microscope, was the added and quite appreciable limitation of the resolving power, due to the imperfection of the observed surface under the conditions of investigation. Where the surface shows roughness — as most surfaces do when heated (temperature etching) — local deformations of the electric field occur, which act as extra lenses and may impair the sharpness of the image at the points affected (*fig. 2*). Owing to this effect it is impossible to expect to be able to distinguish image details smaller than the order of 1000 Å. For most metallurgical investigations this is quite satisfactory: the resolving power is still several times higher than can be attained with the optical microscope. The above mentioned practical limitation, however, implies that there is no objection to supplementing the immersion lens by other lenses — even if the latter are attended by more pronounced image defects — should this be found useful or convenient for constructional reasons. Such extra lenses are used in the Philips emission microscope. Two magnetic lenses are in fact used, with which a total magnification of as high as 3000 × can be obtained without difficulty. The first magnetic lens operates in an unfavourable state of excitation, as will appear later, and is ultimately the factor that limits the resolving power of the microscope. The present resolving power is about 1000 Å.

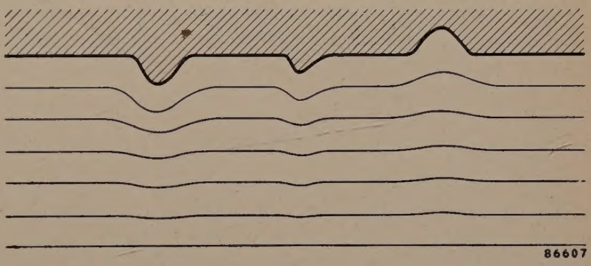

Fig. 2. Equipotential surfaces of the electric field which accelerates the electrons emitted by the specimen and functions as an electrostatic lens. Small elevations or pits in the surface of the specimen give rise to local deformations of the field, limiting the resolving power of the emission microscope.

Contrast in the image

The information that the metallurgist seeks in the electron microscope image of an object is usually concerned with the grain structure and changes which occur when the temperature is varied. For this structure to be visible, not only must sufficient electrons be emitted by the metallic surface, but the emission must vary sufficiently from grain to grain. Sufficiently large differences in emission are not normally found. A homogeneous alloy, provided it emits sufficient electrons, will give an image merely on being heated, in which all manner of lines may be seen that appear to be grain boundaries (*fig. 3*); but such lines usually represent boundaries that had previously occupied those positions and no longer exist at the instant of observation.

A well-known artifice for producing a "contrast" between the grains, which at the same time makes for good emission at temperatures of practical interest, is employed in the Philips emission microscope. It consists in the evaporation on to the surface under investigation of a very thin layer of a suitable metal (activator) which reduces the work function of the surface. The amount of activator adsorbed on to each crystallite surface depends on the orientation of the crystallite. Since the number of electrons emitted is determined almost exclusively by the number of activator atoms, differently oriented grains of a homogeneous material give different electron current densities. By the evaporation of activator atoms on to the surface, the latter is painted, as it were, in various shades of brightness. Moreover the high rate of migration of the adsorbed activator atoms over the surface makes it possible to follow changes in the crystalline structure continuously.

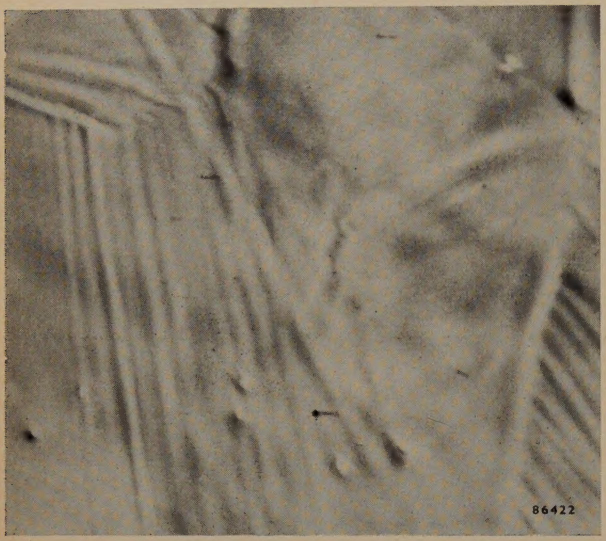

Fig. 3. Photograph of a homogeneous alloy with good thermionic emission. In this case the numerous lines, that might appear to be grain boundaries, are merely grooves in the surface at the locations of earlier grain boundaries.

Thanks to the use of activators with very low work functions (alkali and alkaline earth metals) reasonable emission is obtained even at relatively low temperatures: with barium as activator the working temperature range is 900° to 1200 °C, with caesium it is still lower, viz. 500° to 740 °C.

The activators mentioned are exceedingly reactive, and because of this, care must be taken to exclude foreign elements from the vicinity of the object under observation. As a consequence, the vacuum is more critical in the emission microscope than in the transmission microscope. Because of the reactivity of the activators this method of increasing contrast will not of course be applicable to all metals. Metals, having a high sulphur content, for example, do not lend themselves to this method of investigation, since the sulphur would react with the activator.

The cathode assembly of the emission microscope differs from that of the transmission microscope not only because of its different optical arrangement and the special provisions for the evaporation of activators, but also because the cathode must be adjustable through considerable distances during the observations, in order to be able to scan the object for interesting details. This is done by moving it in the plane at right-angles to the optical axis, just as in the transmission microscope. In the emission microscope, however a radically different construction is necessary because the object, i.e. the cathode, is at a high electrical potential.

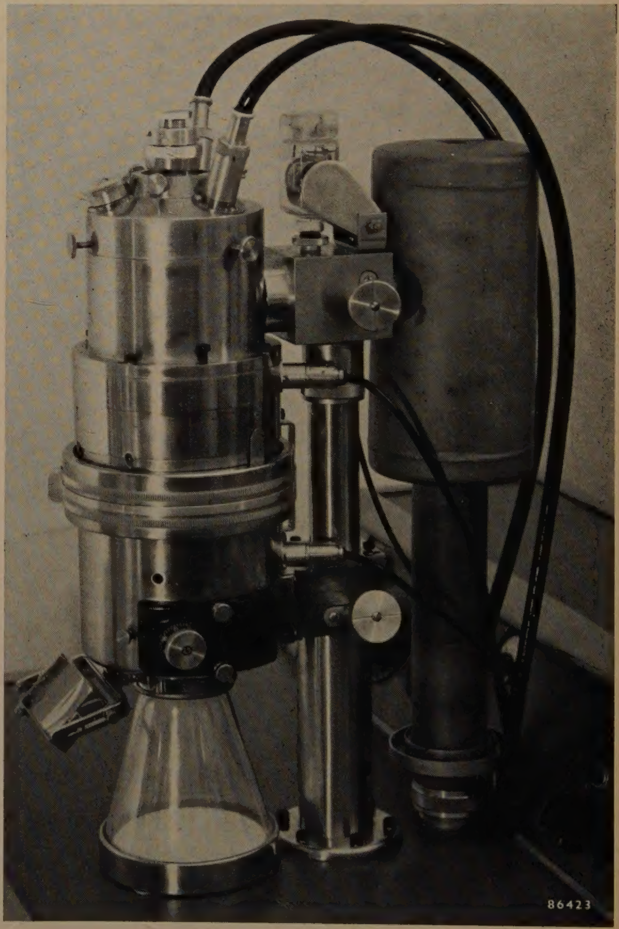

Fig. 4. Microscope tube of the emission microscope (left) and pumping tube with liquid air condenser (right). The lower part of the centre tube, which in the EM 75 kV is connected directly to the high-vacuum pump, now serves principally as a mechanical support fixing the microscope tube to the desk.

Construction of the emission microscope

The vertical microscope tube, together with a part of the vacuum system, is shown in *fig. 4*. A cross-sectional diagram of the microscope tube is given in *fig. 5*. As already stated the design is modelled as far as possible on that of the EM 75 kV transmission microscope. Components peculiar to the emission microscope will be examined here more closely.

The cathode assembly

The cathode chamber in the upper end of the microscope tube is enclosed in an earthed steel jacket. The latter serves also to shield the specimen from any stray magnetic fields from outside, that would give rise to distortion. The low velocity of the electrons at the object, which is a feature of the emission microscope, makes such shielding essential: the deflection of electrons by a magnetic field at right-angles to the direction of movement is inversely proportional to their velocity.

The specimen itself, which is raised to a maximum potential of 45 kV with respect to earth, is mounted in a metal container suspended by three glass insulators from the cover of the cathode chamber (*fig. 6*). The lower part of the metal container forms a flat electrode, which can be regarded as a Wehnelt cylinder and has a small aperture immediately beneath the specimen, through which the electrons pass. The electrons then traverse the field between the Wehnelt cylinder and the earthed anode, which is fitted in the upper pole piece of the first magnetic lens.

For activating the surface of the specimen, four pairs of terminals are arranged about

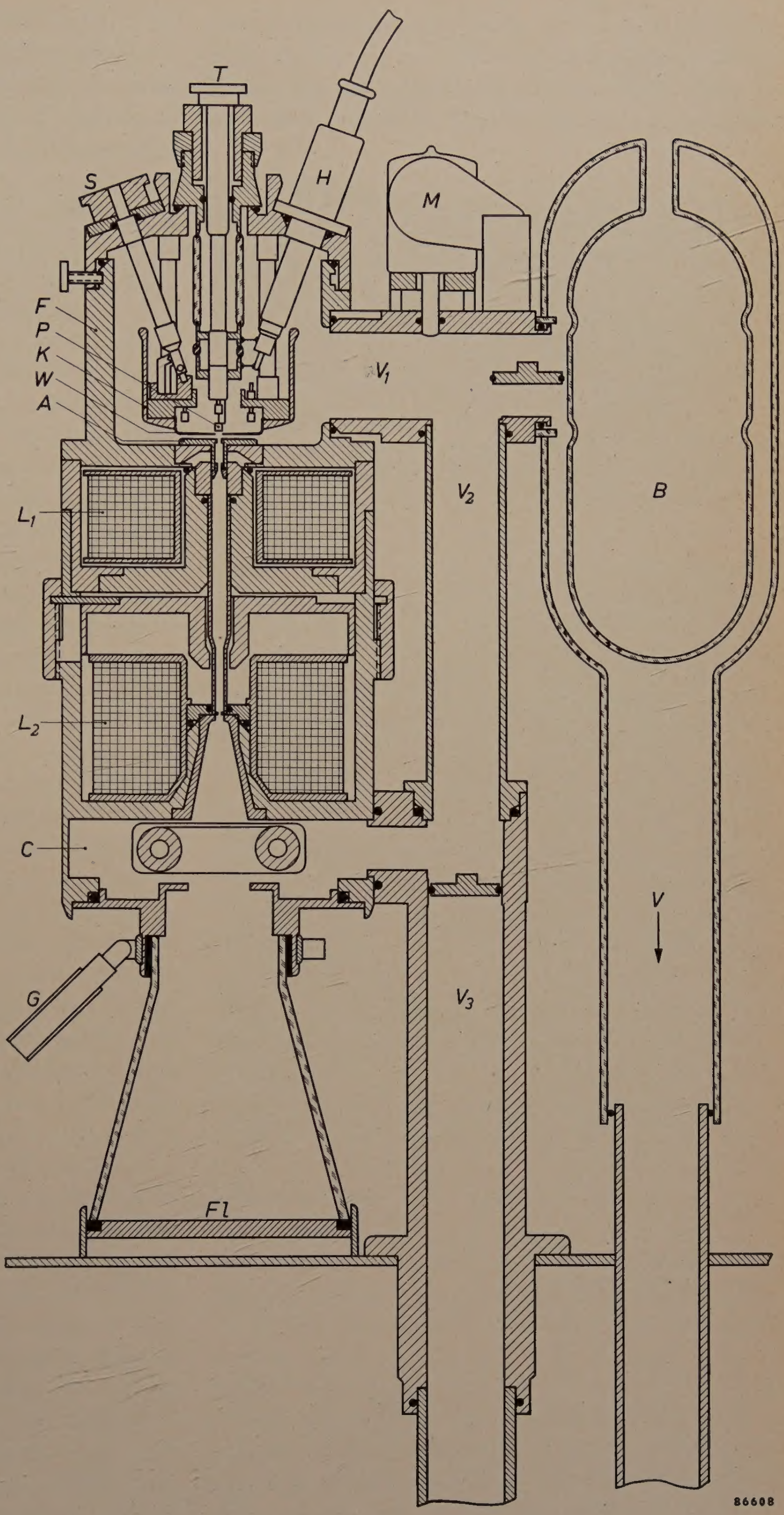

Fig. 5. Sectional diagram of the microscope tube (simplified). *K* cathode container, with the specimen *P* and the Wehnelt cylinder *W*, which are connected via the high voltage cable *H* to the negative H.T. terminal (maximum voltage 45 kV with respect to earth). *A* earthed anode; *F* steel jacket shielding the cathode chamber; *T* specimen holder; *S* switch for the activator heating filaments; L_1 and L_2 magnetic electron lenses; *C* camera chamber; *Fl* fluorescent screen; *G* glass observation lens; V_1 and V_2 pumping tubes communicating with the cathode chamber and camera chamber; *B* liquid air condenser; *V* tube leading to the high vacuum pump; *M* Philips manometer (Penning gauge).

the specimen in its metal container, to which coiled heating filaments can be attached. For activation with barium, a tantalum filament coated with barium beryllate is used. When the filament is heated the beryllate is reduced and the barium is given off as vapour. For activation with caesium, a mixture of caesium bichromate and silicon, packed into a small tube and heated by means of a filament, is employed. Other substances can of course be used as activators, e.g. strontium. The heating current for the filaments, which is drawn from a separate filament supply transformer with special high-voltage insulation, is fed to the cathode container via a separate high-tension cable and plug. An external switch makes it possible to select the most suitable activator for the particular specimen and temperature range, while the microscope is actually in operation. Moreover as soon as one of the four activator sources is exhausted, it is possible to switch over to another.

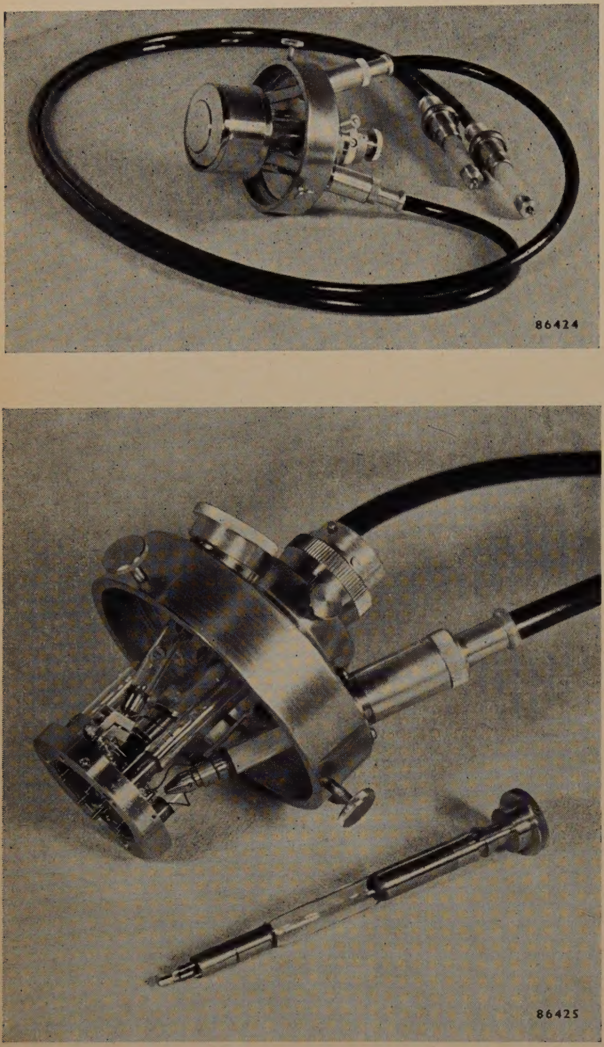

Fig. 6. *Above:* Cathode chamber cover, with the insulated cathode container suspended from it and the high voltage cables (one for the specimen, one for the activators). The Wehnelt cylinder and the aperture through which the electrons make their exit may be seen.
Below: Cathode assembly with cathode container removed; the specimen holder has been taken out (foreground).

When using barium, it is generally satisfactory to activate the specimen prior to observation. When caesium is used as activator it is necessary to keep the source switched on while observing, since the absorbed caesium quickly re-evaporates from the surface of the specimen.

The specimen to be investigated is fashioned in the shape of a small beaker, which can be indirectly heated by an alumina-coated coiled-coil filament placed inside it. This filament is wound non-inductively (as are the activation coils), so that the heater current does not give rise to an interfering magnetic field (see above). The surface to be observed, *P*, i.e. the base of the beaker (see *fig.* 7), is carefully polished to reduce the surface roughness effect described above to a minimum. A mounting bracket is then spot-welded onto the beaker in such a way that when fixed in the specimen holder, the surface *P* of the specimen lies exactly perpendicular to the optical axis. The specimen holder is clamped (but is free to move along its axis) in a glass cylinder, which can be moved laterally, i.e. at right-angles to its longitudinal axis by means of adjusting screws on the outside. The electrically insulated specimen holder, which can be adjusted from the outside via vacuum sealed glands can be rotated about its longitudinal axis and also translated along this axis during observations.

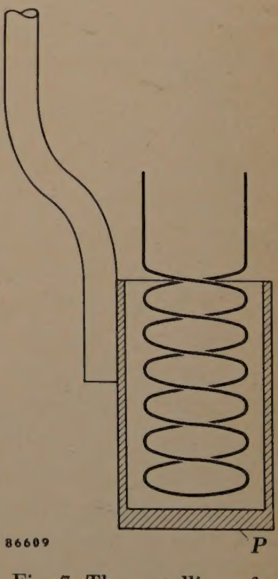

Fig. 7. The metallic surface to be investigated *P* forms the base of a small beaker, in which a heating filament is inserted. The beaker is attached to the specimen holder by means of a rod welded onto the former.

Since the Wehnelt cylinder and its exit aperture remain in the same position during all these manipulations, the lateral displacement and the rotation make it possible to scan a large area of the object surface. This method of scanning, which is possible only with the emission microscope, is in practice far more convenient than the conventional displacement of the object in two directions at right-angles to each other: far fewer movements are necessary for scanning the whole surface (only a small part of which is visible on the screen) and it is considerably easier to re-locate a particular part of the object. The displacement of the specimen holder along the axis permits of accurate regulation of the distance between the object and Wehnelt cylinder; this is of importance in the formation of the image; see below. When one specimen is to be replaced by another, the specimen holder is simply taken right out.

During axial adjustment of the position of the object, it is unnecessary to interrupt the supply of high voltage and heater current to the specimen, but when one specimen is replaced by another the supply must be temporarily interrupted. For this purpose two sleeves, insulated from each other, are mounted on the object end of the specimen holder; when the latter is inserted in the glass cylinder, the sleeves make contact with two contact springs. These contacts are connected via flexible wires to the end of the high-voltage cable in the cathode chamber (see the cross-sectional diagram of the cathode assembly in *fig. 8*).

The temperature of the specimen can be determined quite accurately by means of a thermo-couple or a pyrometer, using a dummy specimen mounted and heated in the same manner, but not raised to a high potential.

The magnetic electron lenses

In the emission microscope the role of objective lens and specimen stage in the transmission microscope is taken over by the magnetic lens L_1 (fig. 5). To reduce image defects it would be preferable to energize the lens fairly strongly; see the article cited in [6]). To do this, a rather novel lens construction with a very wide bore and a very large number of ampere-turns would be needed, in view of the special form of anode necessary to produce an electrostatic accelerating field of the required homogeneity [4]). However to bring the lens construction of the emission microscope more in line with those used earlier in Philips electron microscopes, a lens of relatively narrow bore has been made, which has a sufficiently short focal length and can be sufficiently energized for normal focusing merely by virtue of a somewhat unusual shape of its upper pole piece. In spite of its considerable image aberrations, this lens is quite adequate for the emission microscope, for reasons given earlier.

A second magnetic lens (L_2 in fig. 5), which is practically identical to the projector lens of the EM 75 kV, raises the magnification to the desired value, and also provides a simple means of adjusting the magnification. This is done by varying the gap between the upper and lower pole pieces of the projector lens be means of a milled ring encircling the microscope tube as in the EM 75 kV [5]). In this way the magnification of the lens can be varied continuously between 20 and 90 (i.e. a range of nearly 5; the device employed in the EM 75 kV for increasing this range up to a factor of 9, is unnecessary here).

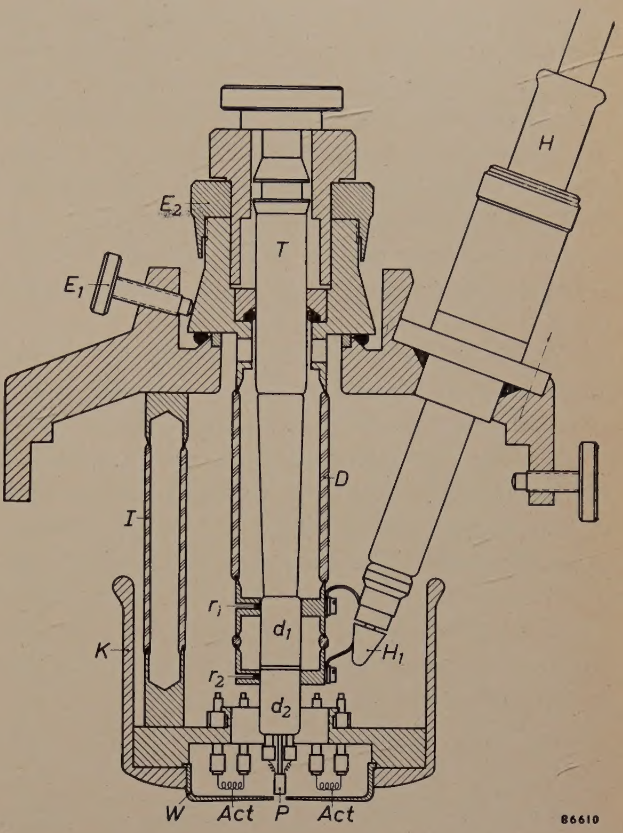

Fig. 8. Cathode assembly (simplified: the sections of the left and right halves do not lie in the same meridian plane). *I* glass insulators; *D* glass cylinder into which the specimen holder *T* carrying the specimen *P* is inserted. By means of screws E_1 the glass cylinder can be displaced in a plane perpendicular to its longitudinal axis. With the screw E_2 the specimen holder is raised or lowered in the direction of its longitudinal axis. The specimen is connected to the high voltage plug H_1 via the insulated sleeves d_1 and d_2 and the sliding contacts r_1 and r_2. *Act* activator filaments, with separate high tension lead for the heater current. Remaining letters as in fig. 5.

The total magnification is usually 150 to 750, the first magnetic lens contributing a factor of 10 and the electrostatic immersion lens a factor of approximately 1. This is when the specimen is in its lowest position i.e. as near as possible to the "Wehnelt cylinder". If the distance is increased by raising the specimen (screw E_2 in fig. 8), while at the same time the magnetic lens is more weakly energized, the total magnification increases, attaining a value of 3000 in the extreme case, when the first magnetic lens is completely unenergized. This is illustrated in *fig. 9*, in which the image formation is depicted under various conditions.

A magnification of 3000 is sometimes useful for visual observation. For photographic work a magnification of 750 is more suitable, with the specimen at its lowest position and with relatively powerful excitation of the first magnetic lens, since under these conditions the field strength at the cathode is greatest (see equation 1). At this magnification the grain size of the photographic emulsion in no way detracts from the resolving power, so that the latter can be fully exploited by subsequent optical enlargement of the photographed image.

As with the EM 75 kV, photographic records are made with a 35 mm film holder mounted in the vacuum space beneath the second magnetic lens. With this arrangement the progress of a phenomenon can be recorded in about 40 exposures. If necessary a phenomenon can be filmed with a ciné-camera, mounted beneath the fluorescent screen at the base of the conical glass end of the microscope tube. The normal metal fluorescent screen must then be replaced by a glass screen, permitting observation of the image from below.

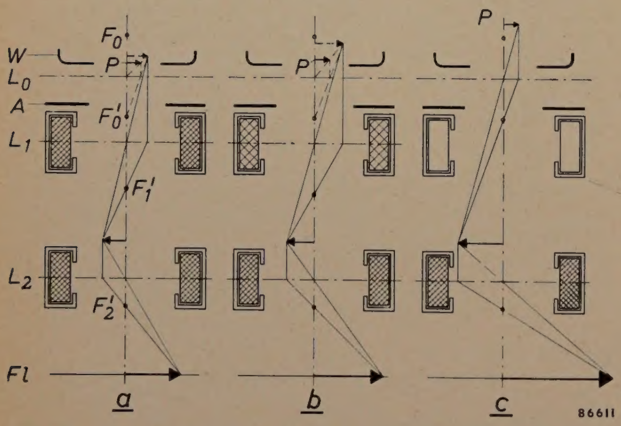

Fig. 9. Image formation in the emission microscope, for different magnifications. (Rotation of the image by the magnetic lenses has been disregarded.)

a) The specimen *P* is as close as possible to the Wehnelt cylinder *W*. The electrostatic lens produces a somewhat enlarged virtual image, which is situated behind the cathode.

b) As the specimen is drawn back somewhat, the image falls back and becomes bigger. The focal length of the first magnetic lens must now be increased, i.e. the lens more weakly energized.

c) When the distance between the specimen and the Wehnelt cylinders attains a given value, the virtual image lies at infinity and changes abruptly into a real image at infinity on the other side, i.e. in front of the cathode. This image approaches the cathode rapidly as the object is moved back still further and soon lies in the object plane of the second magnetic lens. The first magnetic lens is then completely unenergized.

Owing to the very large depth of focus of the electron microscope and the fact that the concentration of the rays is in itself incomplete (limited resolving power), the transition from (*b*) to (*c*), surprisingly enough, is fairly continuous in practice.

The vacuum system

It will perhaps already be clear that in spite of certain similarities, the emission microscope is not so simple to operate as the transmission microscope EM 75 kV. This follows from the very nature of the investigations for which the emission microscope is employed: in these investigations the specimen itself plays an essential role in the optics of the microscope. Many of the simplifications in the EM 75 kV have therefore not been used in the emission microscope in cases where a more complex construction was desirable in the interests of efficiency.

This is especially evident in the vacuum system. On heating a specimen there is always the possibility of rapid out-gassing with the risk of electrical breakdown; measures must therefore be taken, firstly to get rid of any liberated gases as quickly as possible and secondly to minimize the effects of a possible breakdown. These problems are resolved by inserting a liquid-air condenser (*B* in fig. 5) in the vacuum tube just where the latter enters the cathode chamber, which serves to remove any condensable gases. Moreover a mercury diffusion pump is used for production of the required high vacuum. In the EM 75 kV an oil diffusion pump is employed, because, to mention one reason, production of satisfactory high vacua with a mercury pump would entail incorporating a liquid air condenser on account of the vapour pressure of mercury. In the emission microscope, where the condenser is in any case indispensable, the mercury pump is to be preferred, because it precludes the formation of oil films in the cathode chamber, and the deposition of graphite from residual oil vapour should electrical breakdown occur. A rotary oil pump is used as the backing pump. There is no necessity for this pump to run continuously while the microscope is in use, since a vacuum reservoir tank is incorporated; this tank is conveniently accomodated in the desk designed for the EM 75 kV. The mercury pump requires a backing pressure of a few mm of Hg. A mercury switch brings the rotary oil pump in operation automatically, as soon as the backing pressure rises above the permissible value.

It has been found desirable to separate the cathode chamber and the camera chamber as completely as possible; for even after outgassing at 50 °C in vacuo for several hours, photographic film still gives off minute amounts of substances that combine with the activator on the surface of the specimen rendering it ineffective. Within the microscope tube, the cathode chamber and the camera chamber are fairly well separated by the narrow apertures of the two magnetic lenses. Outside the microscope tube, there is ready access between these two chambers via the two tubes that open into them (V_1 and V_2 in fig. 5); but the junction of V_1 and V_2 is located as near as possible to the liquid-air condenser, so that the condensable gases from the film are unlikely to gain access to the cathode chamber. While the microscope is in use a pressure of between 10^{-5} and 10^{-6} mm of Hg is measured at this junction with a sensitive Philips manometer (Penning gauge). (The main function of the vacuum tube V_3 in fig. 5, which in the EM 75 kV leads to the high-vacuum pump, is, in this instrument, to provide the microscope tube with a single robust attachment to the desk. However, V_3 is used at the same time for preliminary evacuation of the microscope tube by the backing pump.)

To avoid electrical breakdowns or, at worst, to minimize the effects of such a breakdown, all surfaces in the cathode chamber are chromium plated, while various components, such as the anode and the Wehnelt cylinder, are made from stainless steel and carefully polished. Such surfaces can easily be cleaned and give off little gas. The anode and the aperture of the first magnetic lens, which is most openly exposed to contamination with vaporized activator, are in one piece; this component can be easily screwed out of the upper pole piece for cleaning.

Stabilization of the high voltage

Stabilization of the accelerating voltage, which always requires care when magnetic electron lenses are employed, is more difficult in the emission microscope than in most transmission microscopes: the investigation of specimens at differing temperatures means that the electron emission and therefore the flow of electrons through the microscope tube must be able to vary within wide limits, without substantially affecting the potential on the tube.

A stabilizer suitable for this instrument has been designed by S. van der Meer of the Research Laboratories in Eindhoven, and is illustrated in the simplified diagram in *fig. 10*. The high voltage generator B, supplied by the mains, delivers a maximum direct voltage of about 45 kV. Fluctuations in the output voltage V_B of B which occur as a result of rapid mains voltage fluctuations, etc., are almost fully compensated by the output voltage V_A from a D.C. amplifier A connected in series with V_B. The principle of this control circuit has been discussed several times in this Review [7]) and is briefly recapitulated in the caption to fig. 10.

This control circuit in itself is not enough because the voltage may vary considerably: changes in load and fluctuations in the mains voltage can give rise to a variation in V_B of several kV (3 kV on passing from no load to full load), if no precautions are taken. The amplifier A, of course, is unable to deliver such a high compensating voltage V_A, and an additional control is therefore incorporated in the circuit in the form of a variable impedance C, connected in series with the primary side of the high voltage generator B. The impedance is so controlled by the voltage V_A, that variations in the input voltage to the high voltage generator compensate for the variations in V_B, and the amplifier A can never be overloaded. Control via C has a somewhat delayed action, but this is no objection, since large variations, such as occur on raising the cathode temperature of the microscope, are always fairly gradual. The rapid fluctuations, on the other hand, are never large and can therefore be met by control A.

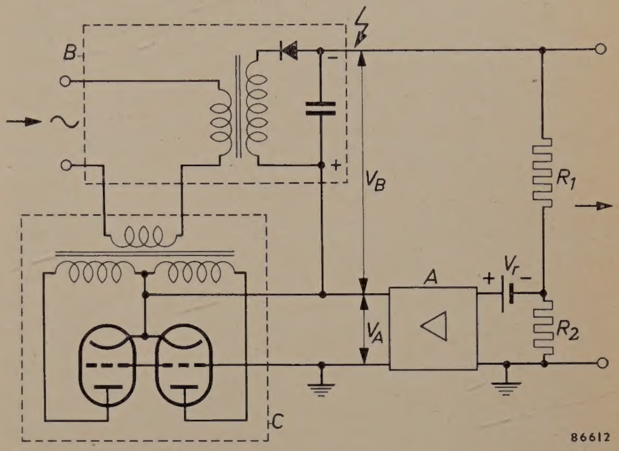

Fig. 10. Circuit diagram of H.T. voltage regulator. B high tension generator, with output voltage V_B. A fraction of this voltage, nominally equal to the reference voltage V_r (a few tens of volts) delivered by a battery, is tapped off through the voltage divider R_1-R_2, and the difference between V_r and the voltage tapped off is supplied to the D.C. amplifier A. The output voltage V_A fluctuations in which are opposite in sign to the input voltage, is in series with V_B, so that rapid variations in V_B are compensated by opposing variations in V_A. The unavoidable residual variations of $V_B + V_A$ are very small, provided the amplifier A has a sufficiently high amplification factor. The variable impedance C, controlled by V_A and regulating the input voltage to the high voltage generator, compensates large slowly-occurring variations in V_B, resulting from load variations and mains voltage fluctuations.

The relative constancy of the high voltage obtained with this circuit is better than 1 : 3000 within half a minute. This is adequate for the purpose.

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[7]) See A. C. van Dorsten, Philips tech. Rev. **10**, 135-140, 1948/49.

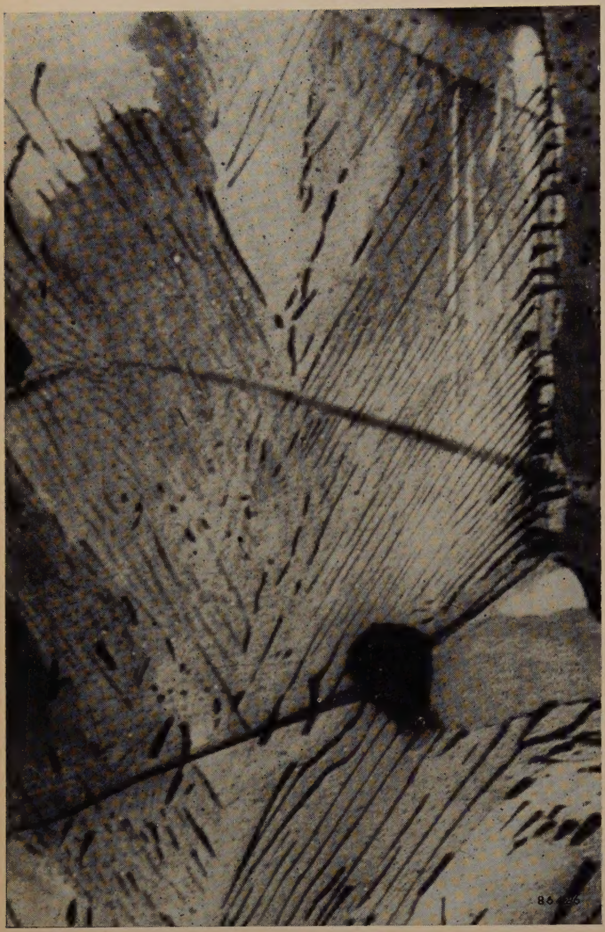

Fig. 11. Photograph taken with the aid of the Philips emission microscope showing the transition of carbon steel from austenite into perlite. Magnification about 2500 ×. The resolving power here is somewhat better than 1000 Å.

The energizing currents for the magnetic lenses must also be stabilized. This is achieved by means of a circuit described earlier [8]).

A number of reports on investigations carried out with the emission microscope described above, have been published, one having appeared in this journal [9]). A photograph made with the present microscope is shown in *fig. 11* and gives an idea of the image quality obtained.

The assistance of A. C. van Dorsten and his co-workers A. Verhoeff, A. J. J. Franken and J. E. Jansz, all of the Eindhoven Research Laboratories has been of great value in the development of this microscope.

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[8]) Philips tech. Rev. **12**, 33-51, 1950/51.

[9]) G. W. Rathenau and G. Baas, Physica **17**, 117-128, 1951; Métaux **29**, 139-150, 1954; Acta Met. **2**, 875-883, 1954; G. Baas, Demonstration of the austenite-pearlite transformation by means of the emission electron microscope, Philips tech. Rev. **16**, 337-339, 1954/55.

Summary. Description of an emission electron microscope, having a resolving power of about 1000 Å and an (adjustable) magnification of up to 3000 ×. After a brief review of the theoretical and practical limitation of the resolving power by electron-optical considerations, the nature of the objects to be examined is discussed in greater detail. Since this microscope is primarily intended for the investigation of metals at high temperatures, thermionic emission is used. Activators such as barium or caesium evaporated on to the surface of the object, ensure adequate emission in temperature ranges of practical interest, and likewise produce differential emission from the variously oriented grains of a polycrystalline metal (contrast). The construction of the cathode permits the use of four different activators while the microscope is actually in use, scanning of wide areas of the object surface and variation of the degree of magnification by adjusting the field of the first electron lens (an electrostatic "immersion lens") Apart from this lens, the electron-optical system employs two magnetic lenses, the second of which is practically identical with the projector lens of the transmission electron microscope EM 75 kV and, as in the latter, permits variation of the magnification. The emission microscope resembles the EM 75 kV, in many other details of its construction. Nevertheless there are fundamental differences in the vacuum system and the system for stabilizing the accelerating voltage of 45 kV. The demands made on both the vacuum system and the voltage stabilization are far higher for the emission microscope than for the transmission microscope .

LIGHTING IN TRAINS AND OTHER TRANSPORT VEHICLES WITH FLUORESCENT LAMPS

by L. P. M. ten DAM and D. KOLKMAN.

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The tubular fluorescent lamp is a light-source of high efficiency and long useful life. These are indeed the main reasons for its large-scale adoption for the lighting of houses, shops, offices, streets, and so on. One particular field into which the fluorescent lamp has quite recently been introduced is in the lighting of land transport vehicles and small ships. The storage battery which serves as the source of energy in these cases will of course deliver direct current and will also have a rather low voltage. Lamps and auxiliary equipment therefore had to be specially developed for this field of application.

The power for electric illumination in trains, buses and small ships is supplied by storage batteries, charged by a dynamo. Since the batteries can deliver only a limited amount of energy, lighting in these vehicles was rather poor while designers were restricted to the use of the filament lamp.

An improvement became theoretically possible when some 20 years ago a new light-source with a considerably higher efficiency came on the market — the fluorescent gas discharge lamp. It was, however, not possible to use it at that time in trains and other transport vehicles, since the first lamps of this type were developed exclusively for alternating current. Direct current lamps did appear later, but their ignition voltage was higher than the voltage of the battery equipment normally used in trains, ships, etc. Only recently have fluorescent lamps and ballast equipment been developed for battery supplies of comparatively low voltages. Such lamps are the Philips "TL" C lamps, operating on 72, 100 and 100 V.

Another system which is used where the voltage of the battery is lower than 72 V (e.g. 24 V) is the conversion of the direct current into A.C. with a voltage of about 220 V. In this case normal lamps can be used, but special ballast equipment is necessary for reasons which will appear below.

"TL" C lamps with current regulator, operating on D.C.

Storage batteries such as are used in vehicles show considerable variation in voltage; thus the lighting batteries in trains whose nominal voltage is, for example, 72 or 110 V, may vary from 60 to 105 V or from 80 to 150 V respectively. Fluorescent lamps fed directly from these batteries must be so constructed that they will ignite faultlessly at the lowest voltage of the battery, i.e. 60 V or 80 V. We shall see later how this is achieved.

Apart from the ignition voltage, the working voltage is one of the characteristics of the lamp which can be specified within close limits during design. From the point of view of efficiency it is advisable to choose the working voltage as close as possible to the battery voltage: the loss in the stabilizing resistor — the ballast which must always be included with D.C. supply — is then kept to a minimum. The working voltage of a gas-discharge tube such as the "TL" C type is virtually independent of the current and by using a ballast resistor whose resistance is also independent of the current it is a simple matter to calculate the current through the lamp at all values of battery voltage. This current always varies relatively more than the battery voltage, and the closer the working voltage of the lamp is to the battery voltage, the greater the variations in current. For mains operation, where voltage fluctuations have a maximum of ±10%, a good stability can be obtained by making the working voltage approximately equal to half the nominal mains voltage. The loss in the resistor is then about the same as the power consumption of the lamp itself. This means that with a 72V battery the lamp should have a working voltage of 36 V. Calculation shows that a lamp which consumes 15 W at the nominal battery voltage uses only 10 W at 60 V, but shows the high figure of 29 W at a voltage of 105. The light output of the lamp is approximately proportional to the consumption, and will thus vary by a factor of nearly 3. If the working voltage is placed higher in order to limit the loss in the resistor, e.g. equal to $^2/_3$ of the nominal battery voltage (i.e. 48 V), then the light variations will become even greater; they can in such a case attain a factor of 4.

In practice wide variations in light output are found to be very disagreeable. When selecting the working voltage, a compromise must therefore be sought between the need to achieve high efficiency and that of limiting light variations. This compromise can be favourable affected if in place of a resistance of constant value a current regulator tube (barretter) is used as ballast; in this way the value of the resistance is automatically varied so that the current remains more or less constant during fluctuations in voltage. Very constant current can be achieved with a resistor consisting of an iron filament in a hydrogen-filled bulb [1]). Such a tube, filled with an inflammable gas, would not be permissible in an public transport vehicle however, and moreover the iron filament is not shockproof.

Both these objections have been overcome in the current regulator tubes which have been developed for our purpose. The pure hydrogen is replaced by a mixture of hydrogen and nitrogen, and the iron filament by a coiled tungsten filament; the limits of the current variation are, it is true, not so narrow as those obtainable with iron-hydrogen resistors, but the gas is not inflammable and the filament is stronger. The stabilizing effect is improved and the shock resistance increased yet further by winding the coil on an insulating tubular support (*fig. 1*). *Fig. 2* shows the characteristic of one of these current regulator tubes which have been developed for train lighting; the current is given as a function of the voltage across the tube.

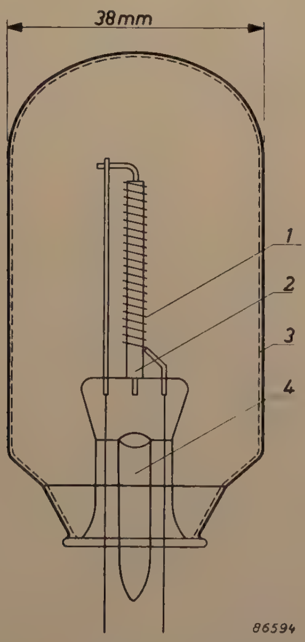

Fig. 1. Cross-section of a current regulator tube for "TL" C lamps. *1* tungsten filament, wound on an insulating pillar *2*. *3* glass bulb. *4* pumping stem. Gas filling: non-inflammable mixture of hydrogen and nitrogen.

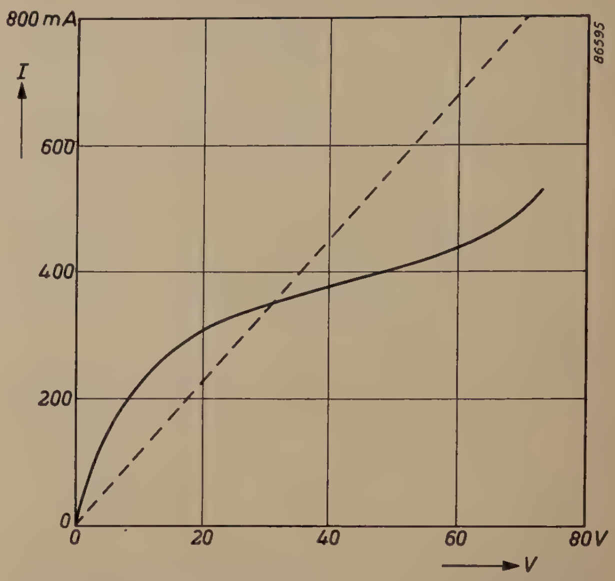

Fig. 2. Solid line: characteristic of one of the current regulator tubes for "TL" C lamps: current I as a function of the voltage V across the regulator tube. For comparison, the dotted line shows the characteristic of a constant resistance.

The use of current regulator tubes has made it possible to set the working voltage of the fluorescent lamps somewhat higher than half the nominal battery voltages, while keeping the variations in light output below a factor 2. *Table I* summarizes the main details of these "TL" C lamps for 14, 15 and 20 W.

The efficiency at a battery voltage of 72 V is about 25 lumens per watt. With incandescent lamps it is only about 10 lm/W; in this connection it should be noted that incandescent lamps require some type of electro-mechanical regulator to prevent overloading, and that a certain loss must occur in this. Apart from the higher efficiency, the "TL" C lamp has the advantage that the electro-mechanical regulator can be replaced by a tube.

Table I: Data on "TL"C lamps for lighting in trains.

Power consump-tion (nominal) W	Battery voltage (nominal) V	Current (nom.) mA	Working voltage V	Length inches	Diameter inches
14	72	370	38	15	1½
15	72	335	45	18½	1½
20	110	355	56	24½	1½

Ignition of the "TL" C lamp

To guarantee ignition at the lowest voltage delivered by the batteries the "TL" C lamp is fitted with special electrodes and connected in a circuit as shown *fig. 3*. With the lamp extinguished, the contact of push-button D_1 is open and that of push-button D_2 closed. When light is required D_1 is depressed and the current flows via D_1 through the starting resistor R_1 (contained in the bulb of the current regulator tube) and the lamp cathode K. The latter consists of a coiled tungsten filament which is longer than that for an A.C. lamp rated for the same current. Thus a sufficiently large part of the battery voltage appears across the cathode for an arc to develop between its extremities. To facilitate the formation of this arc small metal plates are fixed on either side of the cathode (*fig. 4*), which also serve to prevent blackening of the envelope at the ends of the lamp. The gas in the arc across the cathode is ionized so that the main discharge via the current regulator tube R_2 and anode A is easily ignited. (To promote ignition of the relatively long "TL" C 20 W lamp — see Table I — this type has two conductive strips attached to the inside of the glass, each being connected to one electrode.) As soon as the main discharge has started button D_1 is released and the lamp remains alight. To extinguish the lamp it is only necessary to depress button D_2.

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[1]) J. G. W. Mulder, Philips tech. Rev. **3**, 74-79, 1938.

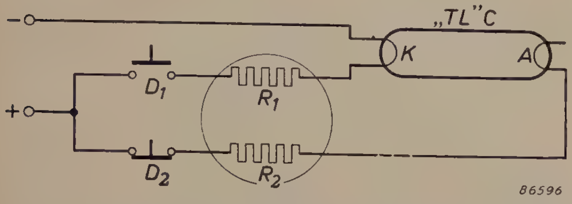

Fig. 3. Circuit of a "TL" C lamp, with cathode K and anode A. D_1 "on" switch. D_2 "off" switch. R_1 starter resistor. R_2 ballast resistor (current regulator tube). R_1 and R_2 are mounted in the same bulb.

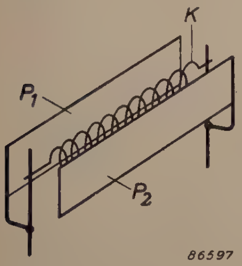

Fig. 4. Small metal plates P_1, P_2 mounted on either side of the cathode K of a "TL" C lamp. These plates assist in the formation of the starting arc across the cathode, and also prevent the blackening of the ends of the tube.

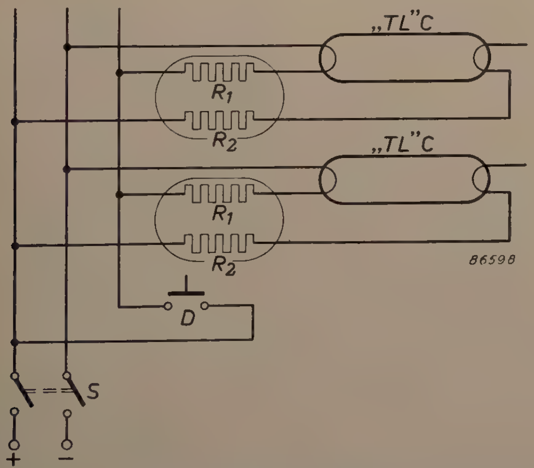

Fig. 5. Circuit for the simultaneous switching of a number of "TL" C lamps, all provided with a starter resistor R_1 and a ballast resistor R_2. After closing switch S and depressing button D all the lamps will light (D may be a time-delay switch which automatically cuts out the cathode heater current after a certain period). Switch S is used to extinguish the lights.

Electrode A of the lamp is exactly similar to K, making the lamp completely symmetrical.

If it is unnecessary to be able to switch each lamp on and off separately, the simple circuit of *fig. 5* can be used (see caption). Combinations of both circuits are also possible so that certain lamps (in the passenger compartments) can be switched on and off separately, and others (in the corridor and toilets) only as a group.

An example of a train installation using "TL" C lamps is illustrated in *fig. 6*.

A.C. lamps supplied via a D.C./A.C. converter

On many railways the battery voltage is 24 V, and in buses the starter battery, also usually 24 V, is used for the lighting. It is not possible to manufacture fluorescent lamps of high efficiency for this very low voltage. In these cases recourse is made to the second solution mentioned above: the D.C. is converted into alternating current and the voltage is then stepped up through a transformer to a value of about 220 V, when standard A.C. lamps can be used.

The centrifugal converter

There are several methods of converting direct current into alternating current. The most obvious one (a motor driving a generator, i.e. a rotary converter) has the disadvantage of a low efficiency, which largely offsets one of the advantages of fluorescent lighting. The vibrator-converter (generally used for car radios) seems attractive by reason of its high efficiency but is not suitable for the power output which is needed here — viz. some few kVA. Similar in principle, but able to cope with the required output, is the centrifugal converter (*fig. 7*) [2]. In this, a rotating jet of mercury makes alternate contact with stationary segments and thus performs

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[2] H. Böhm, Turbowechselrichter mit Quecksilberstrahl für die Stromversorgung von Zugbeleuchtungsanlagen mit Leuchtstofflampen, AEG-Mitt. **42**, 255-259, 1952.
H. Böhm, Stromrichter mit umlaufendem Quecksilberstrahl, E.T.Z. **A 74**, 478-480, 1953.
Another type of D.C.-A.C. converter suitable for this purpose is described in: K. Schmidt, Spezial-Umformer für Leuchtröhren in Fahrzeugen, Elektro-Technik (Würzburg) **37**, 79-81, 1955 (No. 10).

Fig. 6. A restaurant car of the Compagnie Internationale des Wagons-Lits, lit with 15 W "TL" C lamps.

an analogous function to the vibrating contact spring of a vibrator converter. The switching occurs in a sealed steel casing containing a reducing gas at a pressure of more than 1 atmosphere. A small electric motor driving the jet is contained in a second casing also filled with reducing gas but free of mercury. These measures make very little maintenance necessary.

The centrifugal converter is available for outputs from 0.3 to 3 kVA; the photograph of fig. 7 shows the model for 1.5 kVA. The maximum efficiency with the smallest type is about 85% and with the largest type about 90%. The frequency of the delivered alternating voltage depends upon the speed of rotation of the driving motor. A nominal frequency in the neighbourhood of 100 c/s (but not higher) should preferably be chosen, or, alternatively, 64 c/s. The frequency of 64 c/s has the advantage that if connected to a normal mains of 220 V, 50 c/s, the lamp current will be the same as with the converted voltage of 250 V, 64 c/s delivered by the converter; thus, during cleaning or repair of the vehicle in the

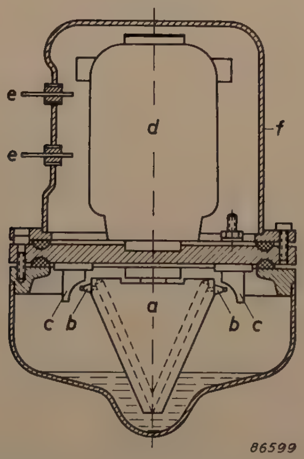

Fig. 7. Centrifugal converter (made by AEG, Germany). *Left:* Cross-section (taken from the article in the E.T.Z. referred to in [2])). *a* rotating cone. *b* nozzles for the two mercury jets (two to give dynamical balance). *c* stationary electrodes. *d* driving motor, with gas-tight current connections *e* through the casing *f*. *Right:* Photograph of a 1.5 kVA centrifugal converter unit.

workshop or depot, the lighting can be connected directly to the mains and not run off the battery (the battery would soon be drained if it supplied lighting with the engine not running). Advantages of 100 c/s are that flicker is less than at 64 c/s and the ballast can be made smaller and lighter. Working at frequencies considerably higher than 100 c/s leads to constructional difficulties in the centrifugal converter.

Ballast equipment for installations with centrifugal converter

The A.C. side of the centrifugal converter behaves in several respects differently from an A.C. mains network:

a) The output voltage is not sinusoidal but of square waveform.

b) The amplitude and frequency of the alternating voltage vary with the battery voltage (and in the same sense as the latter).

c) The switching effect of the rotating jet of mercury implies that voltage and current must pass through zero simultaneously. If the load is such that, with a sinusoidal A.C. supply (of the same voltage curve as that of the converter) the current and voltage do not pass through zero together (power factor < 1), then supply from the converter will cause a transient to occur at the beginning and end of each half cycle. This will cause losses and thus reduce the efficiency.

The ballast equipment must meet the following requirements:

1) The lamps should ignite at the lowest battery voltage (80% of the nominal value) and give sufficient light, while not being overloaded at the highest battery voltage.
2) The lamps should not ignite before the electrodes are heated up (otherwise the electrodes will be unduly damaged each time current is switched on).
3) It should be possible to switch off a large number of the lamps without the remainder being overloaded.
4) The power factor should be approximately 1 when supplied from mains with the same voltage curve as the converter.

We shall consider separately the case where all the lamps are switched on or off together, and the case where it is required that some of the lamps may be controlled individually. Consider first the case where there is only one lamp.

One lamp. Where "TL" lamps are supplied from A.C. mains the ballast usually consists of a choke in series with the lamp. Where supply is from a centrifugal converter the use of this otherwise attractive circuit is not feasible because of the low value of the power factor (see above, sub-section *c*). It is not possible to improve matters with a capacitor across the input terminals, on account of the presence of strong harmonics in the alternating voltage delivered by the converter.

A circuit giving good results is that of Steinmetz (*fig. 8*) which was discussed not long ago in this Review [3]). When supplied with a sinusoidal alternating voltage this circuit has the property that the power factor is 1 if the self-inductance L_1 and the capacitance C are in resonance with the mains frequency and L_2 is equal to L_1. As will be seen below, however, it is desirable in our case to deviate from the condition of resonance.

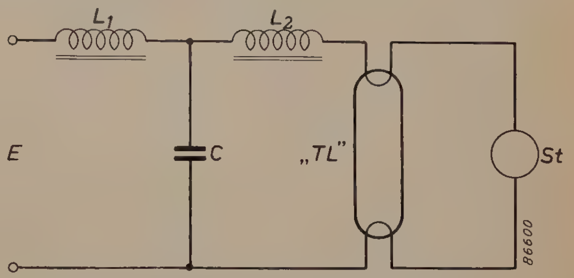

Fig. 8. "TL" lamp (with starter *St*) in a Steinmetz circuit. If L_1 and C are in resonance with the frequency of the sinusoidal alternating voltage E, and $L_2 = L_1$, the power factor is unity.

Some measurements were made with the circuit shown in fig. 8, supplied from a centrifugal converter whose battery voltage E_b and speed of rotation could be varied independently of each other. The rotation speed determines the fundamental frequency f of the alternating voltage. At various speeds E_b was adjusted so that the lamp current remained constant. *Fig. 9* shows the measured values of the alternating voltage E and the power factor $\cos\varphi$ as a function of f/f_0, where f_0 is the resonant frequency $1/(2\pi\sqrt{L_1C})$.

Bearing in mind the necessity for a constant lamp current, it is best to place the working point on the rising portion (*a*-*b*) of the curve for E, i.e. well removed from the resonance ($f/f_0 = 1$); in this region, for constant lamp current, decreasing alternating voltage is indeed accompanied by decreasing frequency, just as in practice a decrease in battery voltage will produce a reduction in both frequency and alternating voltage. It would thus be possible to make the speed of revolution of the motor dependent upon the battery voltage in such a way that the lamp current will remain practically constant over a wide range when this voltage drops. We see, however, in fig. 9 that the power factor in the range *a-b* is relatively low. For this reason, the working point has been placed to the right of the maximum but still off resonance, approximately at *P* ($f/f_0 = 0.9$). It is true that the lamp current is then not constant, but it remains within admissible limits. This has been found from measurements, the results of which will be given presently.

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[3]) W. Elenbaas and T. Hehenkamp, Philips tech. Rev. 17, 288-293, 1955/56 (No. 10).

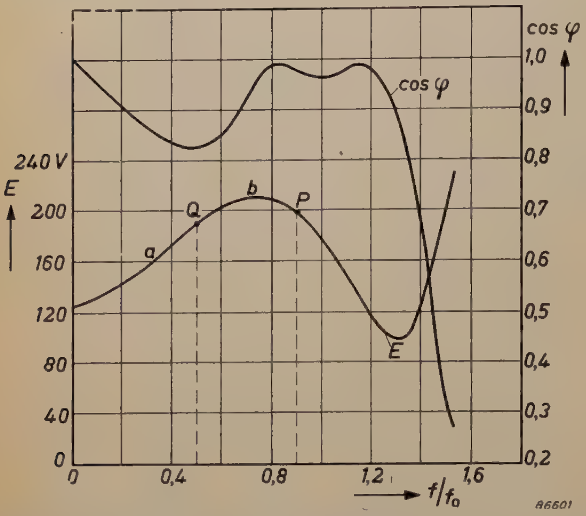

Fig. 9. Measured values of the alternating voltage E (r.m.s. value) and the power factor $\cos\varphi$ in the circuit shown in fig. 8 supplied by a centrifugal converter as functions of the speed of revolution, i.e. of the frequency f. (f_0 = resonant frequency of L_1-C). The battery voltage was so adjusted that the current through the lamp remained constant (420 mA).

Many lamps, all switched on and off together. When a number of lamps n are controlled by a single switch, it is sufficient to make use of a common choke with self-inductance L_1/n and a common capacitor with a capacitance nC where L_1 and C are the values required for one lamp; each lamp has only one individual choke L_2 (*fig. 10*). This arrangement gives a considerable economy in components.

There is one drawback which would be serious in the case of single lamps (fig. 8): although L_1 and C are not in resonance with the frequency of the converter, the voltage across C after switching on, which is also across the still unlit lamp, is so high that the lamp ignites immediately, i.e. before the starter has had time to operate. This ignition with cold electrodes results in a shortening of the life of the lamp. In an installation with a large number of lamps, however, (fig. 10), one or other of the lamps will ignite with cold electrodes when switch S is closed, but as soon as one or two lamps are alight the capacitor voltage has dropped so much that the remainder of the lamps ignite only after a certain delay, via the starter, i.e. with hot electrodes. Some damage is caused, but only to the one or two lamps which ignite first. The disadvantage is therefore relatively less important than in the case of one lamp.

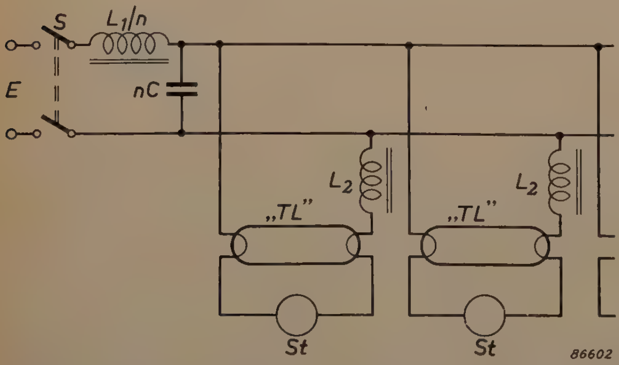

Fig. 10. Circuit for simultaneous control of a number of "TL" lamps n. The common choke has a self-inductance of L_1/n, the common capacitor a capacitance of nC. Each lamp has its own choke L_2 and starter *St*.

Many lamps, some switched individually If it is necessary for some of the lamps to be switched on and off separately (e.g. in railway compartments), it is undesirable, as we have seen above, to connect them as in fig. 8, since the lamps would then suffer too much when switched on. It is better to arrange them as in *fig. 11* where each lamp has its own choke L_2 and its own capacitor C (switched in and out with the lamp), and the n lamps have a common choke with a self inductance L_1/n. When all lamps are switched on the total capacitance is thus nC; the values L_1 and C are again so chosen that $f/f_0 = 0.9$ (fig. 9) and the working point thus lies at P. If now the lamps are switched off one by one, then each time the remaining capacitance is decreased by an amount C, and f_0 becomes higher as a result; the working point shifts along the E curve of fig. 9 to the left. This continues satisfactorily until about 70% of the load is switched off. If still more lamps

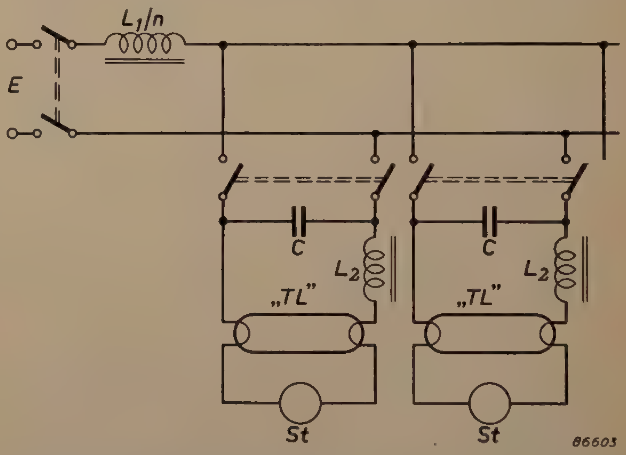

Fig. 11. Circuit for the individual switching of "TL" lamps. Common choke with self-inductance L_1/n (for a total of n lamps); each lamp has its own capacitor C, choke L_2 and starter *St*.

are switched off, a strong fifth harmonic occurs in the lamp current, overloading the remaining lamps. It is therefore necessary for at least 30% of the load to remain in circuit; this is no drawback in a railway carriage since these lamps can be used for lighting the corridor and toilets. When only this basic lighting is burning, the capacitance in circuit is 0.3 nC, giving a resonant frequency of $f_0' = f_0/\sqrt{0.3}$ so that $f/f_0' \approx 0.5$ (point Q in fig. 9). The fact that the power factor is rather low with this value of f/f_0' is now of less importance, since the converter carries a very light load.

For the switching on of the basic load, a similar situation exists as when all the lamps are switched together (see above): only the two lamps which ignite first suffer any damage. Once the basic load is in circuit, individual lamps which are switched on subsequently ignite via the starter, i.e. with pre-heated electrodes.

Results

Fig. 12 shows various electrical and luminous quantities as a function of the battery voltage. These were measured on an installation with a centrifugal converter and "TL" lamps of 40 W, colour "warm white" (colour temperature 3000 °K). The nominal battery voltage is 24 V, the minimum 19 V. The power consumption of the lamp at 19 V is 77.5% of that at 24 V; to make comparison possible it may be noted that the same lamp in a normal circuit with ballast choke and fed from mains with a sinusoidal alternating voltage and constant frequency would consume only 64% of the nominal power with the same reduction in voltage.

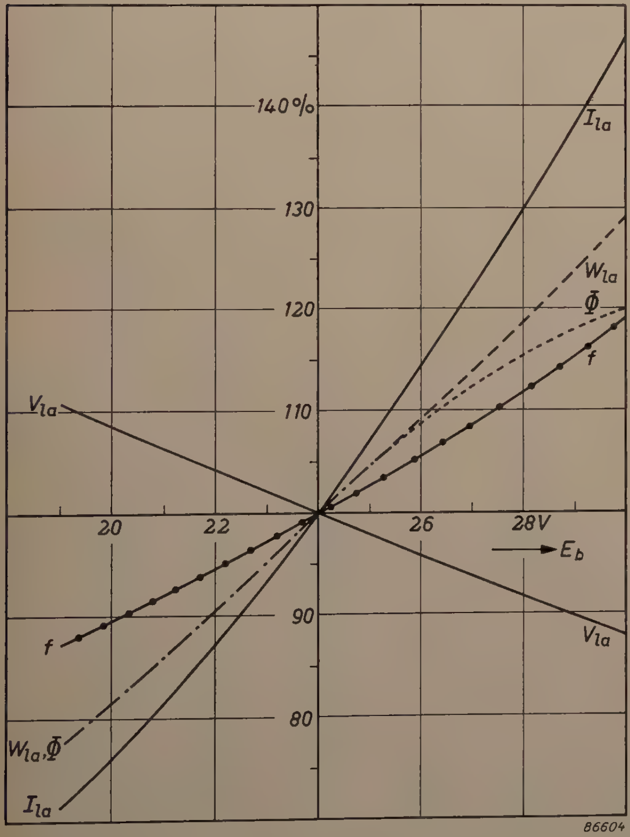

Fig. 12. Various quantities as a function of the battery voltage E_b in an installation with 40 W lamps supplied via a centrifugal converter: lamp current I_{la}, working voltage V_{la}, lamp dissipation W_{la}, luminous flux Φ and the frequency f.

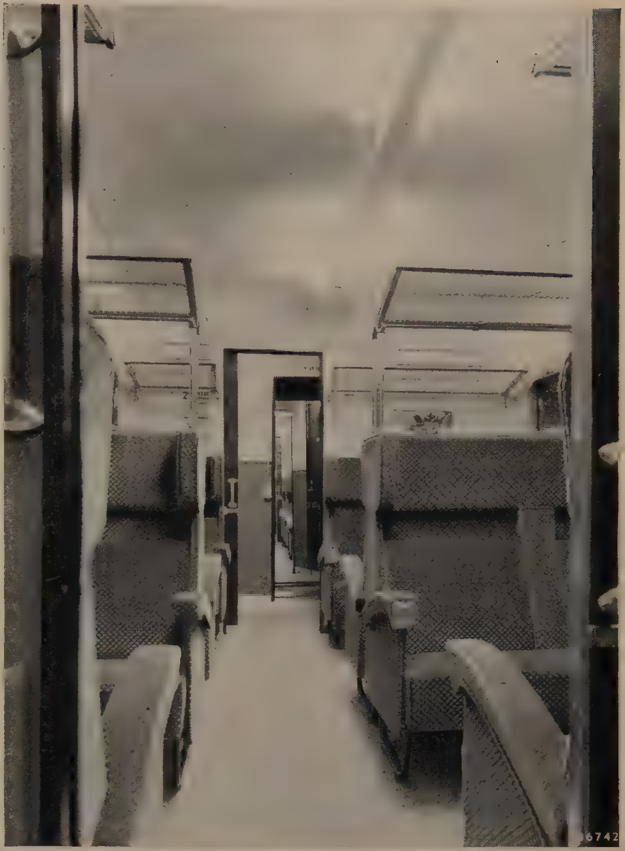

Fig. 13. Lighting in the carriage of an express train of the Netherlands Railways, using 40 W "TL" lamps, fed via a centrifugal converter.

With reference to the output from the battery, the efficiency reaches a value of 45 lumens per watt. With incandescent lamps, as already mentioned, the efficiency is not more than 10 lumens per watt.

With an ambient temperature of 20 °C and a battery voltage of 80% of the nominal value, all lamps ignite reliably. At 0° C ignition can be guaranteed down to 83% of the nominal battery voltage. *Fig. 13* shows a lighting installation using the centrifugal converter.

Starterless circuit

Not long ago a new fluorescent lamp, type "TL" M, with a starterless circuit, was discussed in this Review[3]). This lamp can also be used in conjunction with the centrifugal converter, in the circuit shown in *fig. 14*. The difference between this and the normal “TL” M lamp circuit is that in the latter the choke coil L_1 is omitted and its function taken over by magnetic leakage from the coils L_2. In the present case however it is necessary to retain choke L_1 to achieve a good power factor. By making this common to all lamps in the installation, lifetimes remain satisfactory, even with individual switching.

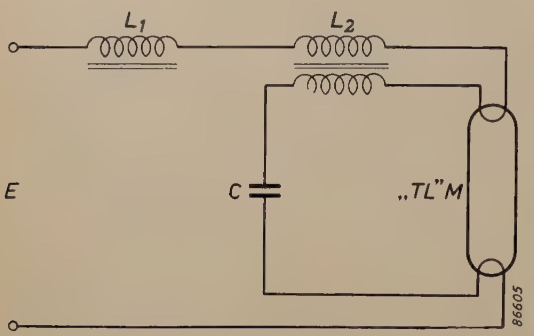

Fig. 14. Circuit for a “TL” M lamp, without starter. On switching on, there is an initial current through L_1, L_2 (whose coils are so wound that the total self-inductance of L_2 is zero), the two filaments and C. Since L_1 and C are close to resonance, the current is considerable and the filaments are thus rapidly heated. When they have reached a certain temperature, the lamp ignites. The currents through the two windings of L_2 are now out of phase, and a certain self-inductance occurs; the circuit then effectively reverts to that of fig. 8 (without the starter).

As a result of the extra losses in the electrodes and the coils the efficiency of an installation of “TL” M lamps is some 15% lower than that of an installation with starters; against this there is the advantage of simplification attending the use of “TL” M lamps, which need no starters.

Summary. During recent years more and more use has been made of tubular fluorescent lamps for the lighting of trains, buses and small ships. Special types (“TL” C lamps) have been developed for battery supplies of 72, 100 or 110 V using a current regulator tube (tungsten filament in a non-inflammable mixture of hydrogen and nitrogen) as ballast. The working voltage of the “TL” C lamps is rather more than half the nominal battery voltage; the regulator tube limits current fluctuations due to varying battery voltage to a factor of 2. “TL” C lamps are manufactured for power ratings of 14, 15 and 20 W. With a battery voltage of 72 V the efficiency is in the region of 25 lumens per watt.

When using 24 V batteries (e.g. the starter battery of buses) the direct current is converted into A.C. by means of a centrifugal converter (rotating mercury jet) of high efficiency, and the A.C. voltage raised to 220 V through a transformer, making it possible to use normal “TL” lamps. The frequency should preferably be either 64 or about 100 c/s; flicker, especially with the latter frequency, is practically nil. The ballast equipment (differing according to whether the lamps are switched on individually or together) is based on a Steinmetz circuit. The efficiency, with reference to the output from the battery, is as high as 45 lumens per watt. “TL” M lamps (starterless lamps) can also be used for illumination in transport vehicles.

A PRIVATE AUTOMATIC BRANCH EXCHANGE USING HIGH-SPEED UNISELECTORS

by B. H. GEELS *).

621.395.264

In large automatic telephone exchanges economy demands that the number and dimensions of the necessary equipment be as small as possible without limiting the facilities available to subscribers. Only with the development of high-speed uniselectors and their associated test-relays, replacing the conventional two-motion selectors, has it been possible to utilize fully the advantages of the so-called indirect systems. The description of a large private automatic branch exchange (PABX) given in this article will elucidate this matter and will also give an idea of the elaborate measures necessary in order to meet all kinds of secondary requirements in a private telephone system. This article will be followed in due course by a description of the high-speed uniselectors and of a public exchange developed along the same lines.

The traffic handled by private branch exchanges can be divided into two main classes, viz. the internal traffic and the incoming or outgoing traffic via the public telephone exchanges. Although the requirements made upon private exchanges as regards internal connections are generally less stringent than those made upon public telephone exchanges (it is not necessary, for instance, to count the calls), the establishment of connections for incoming and outgoing calls via the public lines makes very high demands on the private branch exchange. The development of PABXs has therefore followed entirely different lines from that of public exchanges.

For manual private exchanges there was no reason for any special development: an efficient telephone operator could be expected to cope with the demands of the incoming and outgoing traffic. Although automatic equipment has now been widely adopted for private traffic, the well-known manual exchanges equipped with flexible cords, jacks and plugs are still frequently used for external connections via the public line.

Although manual exchanges with jacks for every extension and for every public line offer the advantage of individual handling of every external call, they nevertheless have many disadvantages. Their operation makes considerable demands on the operator, as she must act promptly both at the beginning and at the end of each call. It may be necessary to employ a large number of operators, if the traffic is very heavy. Finally, the arrangement of the desk becomes confused in large installations on account of their very size. For these reasons the modern development of private branch exchanges aims at the introduction wherever possible of automatic devices for the establishment of local calls whereby the demands made on the operator are reduced. In this way the cost of operators is cut to a minimum, and in addition local calls are handled in a much shorter time.

The development of the PABX type UB 49 is also based on this principle. By the use of various modern components developed by Philips Telecommunications Industries since the war, it has been possible to incorporate in this exchange a number of important features [1]).

In order to appreciate these features it is necessary to discuss the development of automatic telephone equipment and in particular that of private automatic branch exchanges. The function of elements such as final selectors, group selectors, line finders, pre-selectors, etc., which form the component units of all automatic telephone exchanges is briefly explained in the diagrams in fig *1a* and *1b* for those readers who are not acquainted with these matters.

Direct systems

The first automatic telephone system was developed by the American Strowger. The systems derived from this original Strowger system, which have been very widely applied, are called *direct systems*, because the dial pulses from the caller's extension are used directly for the positioning of the automatic telephone selectors [2]).

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*) Philips Telecommunication Industries, Hilversum, The Netherlands.

[1]) A description of the PABX type UB 49 by the same author appeared in Communication News **15**, 2-19, 1954 (No. 1).

[2]) See for example, J. Atkinson, Telephony, Pitman, London 1952.

Direct systems have the advantage of a relatively simple design and for a long time it was considered that they were the fastest type of system. Direct positioning of selectors ensures that the connection is established as soon as the subscriber has dialled the last digit of the required number and practically immediately afterwards the ringing current is applied to the called person's telephone. On closer examination, however, it will be found that the rapid action of these systems is illusory, as the telephone dial functions relatively slowly. The selectors of the direct systems are only just capable of following the dialling pulses, but as the subscriber does not realize the fact that time also passes during the dialling operation, he gets the impression that the establishment of a connection takes no time at all. If the modern selecting methods were to be used, however, the selectors of the direct systems would no longer be able to follow the selecting signals, which are much faster in the modern systems.

The nature of the direct systems is such that a number of devices are necessary for positioning the selectors and, after having established the connection, remain engaged although inactive during the entire call. Consequently, a relatively large number of these devices are necessary in the exchange and it is difficult to design them so as to be cheap to make.

The selector normally used in direct systems is a modified version of the Strowger two-motion selector (*fig. 2*). It has 100 outlets, so that 100 subscriber's lines can be connected to it. The selector must then react to two series of dialling pulses i.e. two digits of the required number. In order to make all the 100 outlets accessible in this way they are arranged in 10 rows of 10. The brushes of the selector can be moved by means of two electro-magnets which may be termed the vertical magnet and the rotary magnet. The pulses relating to the first digit are passed to the vertical magnet via the contacts of relays forming part of the selector circuit. The magnet lifts the brushes step by step till they face the row of outlets corresponding to the first digit. Some relay contacts are then tripped, so that the dialling pulses of the second digit are fed to the rotary magnet. The brushes then rotate step by step in a horizontal plane touching the contacts of the row as they pass, until they connect with the contacts of the desired subscriber. Since the positioning mechanism is discontinuous, the not inconsiderable mass of the brush mechanism must be accelerated and stopped again and again. The pulse repetition frequency, therefore, must not be too high: otherwise the selector will not be able to follow the pulses. For this reason a pulse repetition frequency of only 10 pulses per second was used in most direct systems.

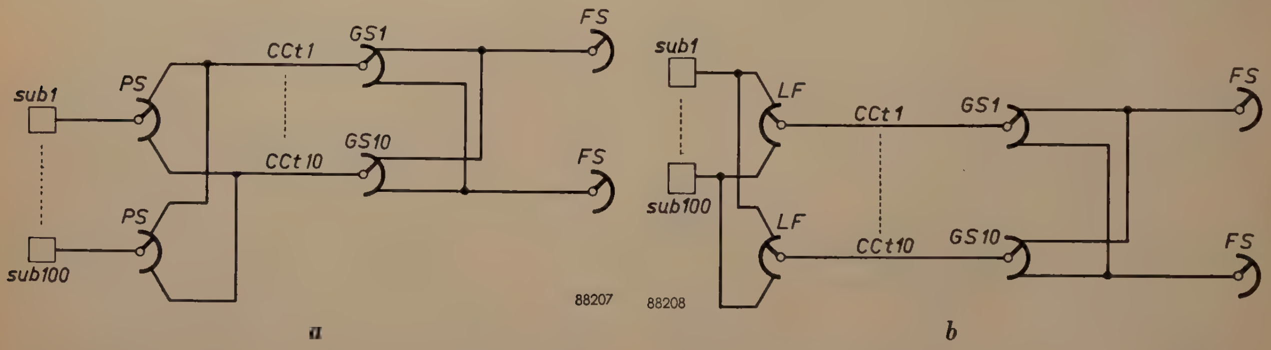

Fig. 1. Schematic diagrams illustrating automatic telephony. The extensions (sub) connected to a telephone exchange are mostly divided into groups of one hundred, which are then connected to the contact banks of selectors having 100 outlets (final selectors *FS*) to enable them to be selected.

If the exchange is equipped for 100 to 1000 subscribers the final selectors *FS* are preceded by the group selectors *GS*; in this way it is made possible to choose a free final selector to the desired group of 100 subscribers. In the case of 1000 to 10,000 subscribers it is required to introduce another group selector stage preceding the first one in order to make it possible to select a free group selector to the desired group of 1000 subscribers.

Consequently, to establish the desired connection the subscriber must have a group selector at his disposal. Only a small number of subscribers make a call at the same moment; it is, therefore, wasteful to connect every set to the brushes of a group selector. The subscriber's lines are therefore connected to a considerably smaller number of group selectors via one or more reducing stages consisting either of pre-selectors or of line finders. The number of group selectors depends on the average number and duration of the calls in the busy hour. It may be necessary, for example, to provide a group of 100 subscribers with 10 group selectors.

a) If pre-selectors (*PS*) are used as a reducing stage, then the contacts of each pre-selector are connected to the brushes of the 10 group selectors via cord circuits (*CCt*), while the brushes of each pre-selector are connected to a subscribers' line. In this case 100 pre-selectors with 10 outlets are thus required for a group of 100 subscribers. If a subscriber lifts the receiver, then the brushes of the pre-selector relating to this subscriber start hunting the contacts; they stop at the contacts leading to the first free group selector. A relay, the test relay, which is consecutively connected to the various group selectors by the pre-selector, is provided for checking whether a group selector is engaged or disengaged. If the test relay is connected to a disengaged group selector, then it is energized, on account of which the pre-selector comes to a standstill. (In order to prevent existing calls via engaged group selectors from being disturbed by the testing, this is done not via one of the two speech lines, but via a third line and a third contact bank of the pre-selector.)

b) If line finders (*LF*) are used as a reducing stage, their contacts are connected to the subscriber's lines, while their brushes are connected to those of the group selectors. Consequently in this case 10 line finders with 100 contacts per bank are required. If the receiver is now lifted, the brushes of a free line finder start rotating along the contacts in order to hunt the calling subscriber. For this purpose a test relay connected to a brush of the line finder is connected in turn to the line circuit of the various subscribers. As soon as it is connected to that of the calling subscriber, the relay is energized and in this way the line finder is brought to a standstill.

Indirect systems

In *indirect systems*, as the name implies, the principle of direct control of selectors by the dialling pulses is no longer applied. The dialling pulses are instead received by a central switching device (register or director) which is connected to the cord circuit. The register can start positioning the selector only after it has wholly or partly received the number that the caller desires. As a consequence of this it is, in general, impossible to avoid some delay between the termination of the last series of dialling pulses and the establishment of the connection, though the selectors used in indirect systems are no slower than those of direct ones.

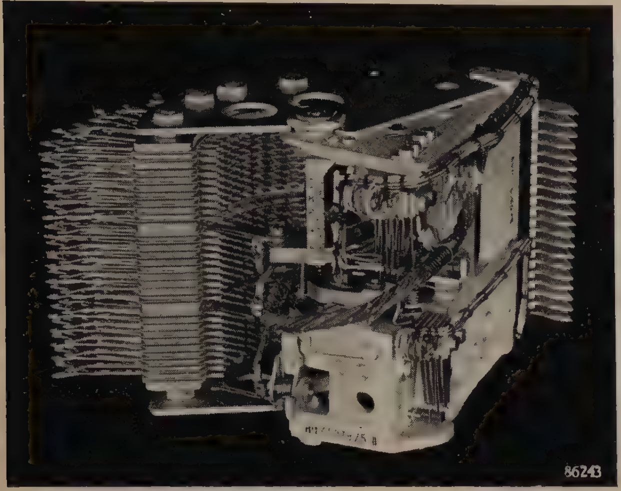

Fig. 2. Two motion selector. The contact bank with 3 × 100 contacts can be seen on the left; in the centre are the three brushes.

A second cause of delay in the indirect systems is the fact that in general they are designed as line finder systems, whereas in the direct systems pre-selectors are more usual. The latter have only a small number of contacts whereas line finders have a large number of contacts (see Fig. 1*a*-*b*); hence positioning of a line finder will, on an average, take more time than that of a pre-selector.

Although the indirect systems commonly used up till now have had the drawback of a somewhat slower operation as compared with the direct systems, the use of registers nevertheless offers many advantages. These central switching devices are only active while the connection is being established and for that reason they are only engaged for a few seconds during every call. The consequence of this is that it is not necessary to equip all cord circuits with a register of their own: a small number of registers will suffice for a large number of simultaneous calls. The registers are connected to the cord circuits (*CCt*) via a reducing stage, the cord circuit finder (*CCtF*); see *fig. 3*. (It is true that this finder is a further cause of delay, because it must first be positioned before the subscriber hears the dialling tone, which is the signal that he may start dialling.) As the required number of registers is small, their complexity has only an insignificant influence on the cost of an automatic exchange. On the other hand there is the great advantage of indirect systems that the provision of special facilities is simpler and less expensive than in the case of direct systems. Some of these facilities will be discussed below.

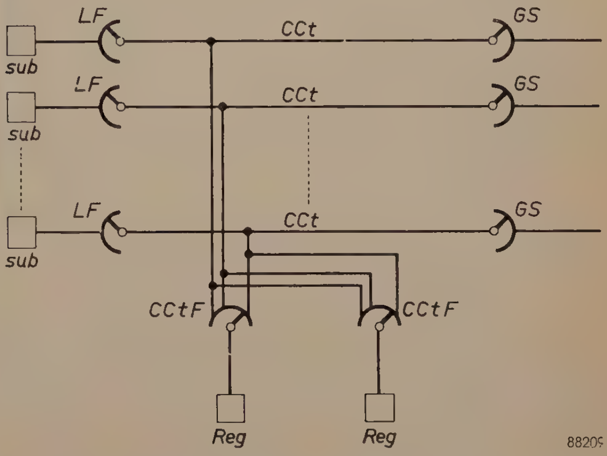

Fig. 3. Connection of the register *Reg* to the cord circuits *CCt* with the cord circuit finders *CCtF* acting as a reducing stage. The other letters correspond to those of fig. 1.

Outgoing traffic

If it is required that outgoing calls are established automatically, i.e. without the intermediary of an operator, this imposes certain special requirements on the selectors. In general, it is further required that outgoing calls can be made automatically only from a number of specified extensions. This means that the selectors must then be able to distinguish between those extensions from which outgoing calls may be made automatically and those from which they should pass through the operator. Yet another subdivision of the former group is desirable, viz. the extensions from which trunk calls may be made automatically and those from which these calls should pass through the operator. Finally it may be desirable to block altogether outgoing calls via the operator from certain extensions (normally the operator can connect any extension with an external number by first obtaining the latter via the public line and then connecting the extension by dialling the internal number).

The many special requirements thus imposed on the selectors and the various circuits imply a certain preference for an indirect system. The demands made by incoming local calls confirm this preference.

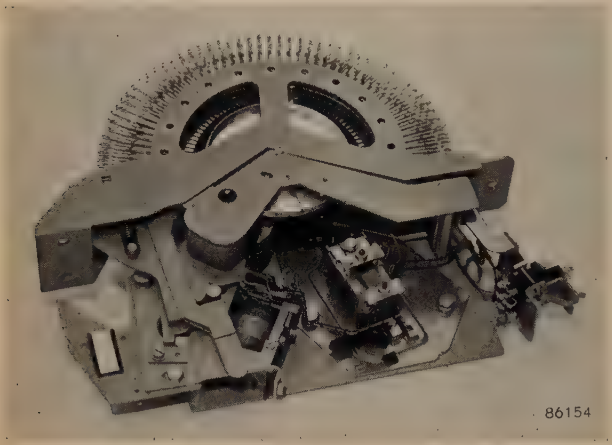

Fig. 4. High-speed uniselector U 45A with four brushes. Other versions exist with more brushes.

To avoid the necessity for bulky cord desks for incoming traffic, modern private automatic branch exchanges are designed so as to be able to handle incoming calls via the automatic equipment. In this way the operator's task, which nowadays consists almost exclusively of answering the incoming calls and dialling the desired internal number, is lightened. However, it is very desirable to have a quicker method for setting up a number than dialling. For this purpose push-button panels have been developed which render it possible to transmit a digit by merely depressing a button. It is not possible to make direct use of the electric signals from the push-buttons for the positioning of the selectors: the signals must first be applied to a register which in turn enables the connection to be established. Some private branch exchanges have been developed that use the direct operation methods for private traffic but push-buttons panels and registers for the incoming local calls. Clearly it is more advantageous, both from a technical and an economical point of view, if registers are used throughout (preferably the same ones being used for both incoming and outgoing traffic). This is the case with the private branch exchange UB 49. Moreover, the development of fast uniselectors and relays have made it possible to speed up the whole register system, the slow response of which was a drawback of earlier indirect systems.

The principal new component is the high-speed uniselector U 45A shown in *fig. 4.* It is a selector with 100 outlets. As it only makes one single rotary movement, its construction is simple and it has the very high speed of 300 contacts per second, as a result of which the selector can hunt all its outlets in only $^1/_3$ of a second. It is driven by clutching the rotor of the selector to a continuously-rotating spindle which extends through a number of selectors mounted in parallel. The clutching is controlled by the appropriate register.

The selector is thus not driven step by step, as is the case with the two motion selectors used in direct systems. Here the selector is driven uniformly and as a consequence it runs smoothly in spite of its high speed, which is most important from the point-of-view of wear. Using this high-speed selector reduces the delay between lifting the receiver and hearing the dialling tone to an average of 0.5 sec. Similarly, after the last digit is dialled, the connection is established and the ringing current is then applied within an average time of 0.5 sec. Apart from this obvious advantage, the high speed uniselector possesses other desirable characteristics; these will be discussed later.

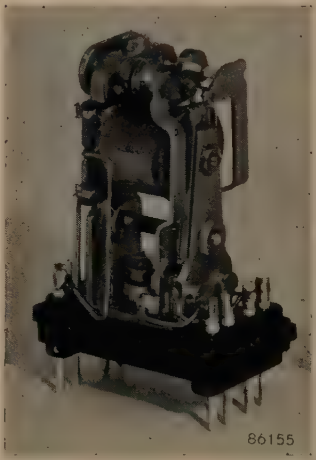

Fig. 5. High-speed relay, type S 50.

A very fast-acting test relay is required to make it possible to stop the selector (running at a speed of 300 contacts per second) stop at any desired contact without error. The relay S 50 shown in *Fig. 5* was developed for this purpose. In an appropriate circuit this relay opens its break contact 0.3 millisecond after the actuating current is switched on. To make possible this extremely high switching speed the relay is of very light construction, yet it is very robust and has a normal contact pressure (20 grams).

The private automatic branch exchange UB 49

This system may best be described with the aid of a diagram showing the connections of a PABX for more than 100 extensions (*fig. 6*). The various possible connections will now be dealt with in turn.

Internal connections

For each extension there is a line circuit (*LCt*) which is connected both to appropriate contacts on 15 (or less) line finders and to contacts on the same number of final selectors [3]).

If there are more than 100 cord circuits, then a second cord circuit finder may be introduced as shown in fig. 6. It is then possible to connect 200 cord circuits.

When the receiver is lifted from an extension, a signal is sent via the corresponding line circuit (*LCt*) to the call detector (*CD*) which, in turn, applies a starting signal to a register (*Reg*) appropriate to this call. The appropriate register is determined by a call distributor or allotter (*All*).

As soon as the register in question receives a starting signal from a call detector, it causes its cord circuit finder to start hunting a free cord circuit whose associated line finder gives access to the group of 100 to which the caller belongs. These free cord circuits are marked as being free by applying a voltage to their contacts in the cord circuit finder via *1*. The cord circuit finder is stopped on the contacts of a free cord circuit, by means of a high-speed test relay (type S 50) in the register which is actuated by the marking voltage. When the cord circuit finder has found a free cord circuit, the register starts the line finder of that cord circuit. Now the line relay in the line circuit of the caller's line is activated: hence the callers line in the contact bank of the line finder is marked by a voltage via *2*. This voltage again actuates the test relay in the register, as a result of which the line finder comes to a standstill at the caller's contacts.

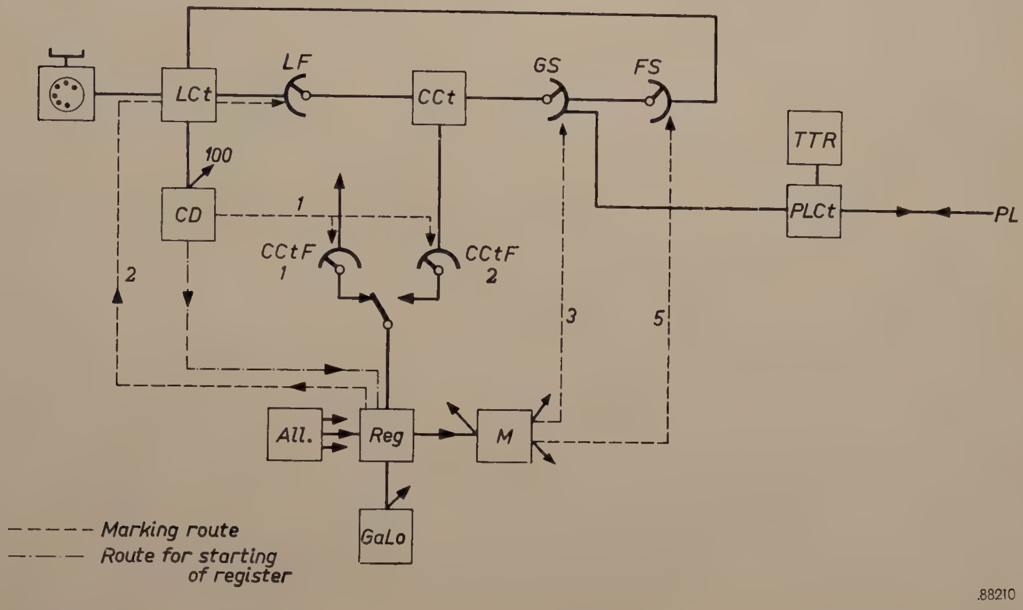

Fig. 6. Schematic layout of a PABX type UB 49 for more than 100 connections. *LCt* line circuit for each extension, *LF* line finder, *CCt* cord circuit, *GS* group selector, *FS* final selector, *CD* call detector, *CCtF* cord circuit finder, *All.* call distributor, *Reg.* register, *GaLo* gate lock-out, *M* marker, *PlCt* public line circuit, *TTR* circuit for blocking outgoing automatic trunk calls (trunk traffic restrictor).

Both the line finders (*LF*) and the final selectors (*FS*) are rotary switches with 100 outlets; the extensions are therefore conveniently subdivided into groups of a hundred. A call detector (*CD*), which comes into action as soon as the caller wants to make a call is provided for each group of 100 extensions. A cord circuit (*CCt*) is permanently connected to the brushes of each line finder. This will be explained presently. The cord circuit is also connected to the brushes of a group selector (*GS*) giving access to a number of final selectors and to a number of public line circuits (*PLCt*). All cord circuits are connected to the contact banks of cord circuit finders (*CCtF*) by means of which a register can be connected with any required cord circuit.

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[3]) The selection of this number depends on the number and duration of the calls made by a group of 100 extensions during the busy hour.

As was stated earlier, the extensions are divided into several classes according to whether they are granted the facility of automatic outgoing and/or trunk calls. At the moment the line finder tests the callers' line, the register also determines the class to which the caller belongs. For this purpose class identification wires ("identification multiple") pass along the rows of registers; the appropriate register is connected to these wires at the moment it is designated by the call distributor. In view of the fact that more than one register can never be *simultaneously* active in searching for a caller, it is never possible for more than one register to be connected to the identification multiple at the same time. For every class to be identified there is one multiple-wire and one class relay per register. In every line circuit the contact of the line relay that is to carry the marking voltage to the contact bank of the line finders is connected, by means of a wire, to the multiple-wire of that particular class to which the extension belongs. The caller's line is now marked in the contact bank of the line finder by a voltage from the register via the particular class relay that is connected to the contact of the line relay in the line circuit by means of its multiple-wire. Consequently, both the test relay and the class relay in the register are actuated in the same circuit. As soon as one of the class relays is actuated, the connection between the register and the identification multiple is broken and then the call distributor is in a position to designate another register for answering a call.

In the method of identification described above every possibility of incorrect identification is excluded, as at any given moment only one register is connected to the multiple. This also means that only one register at a time is ever engaged in positioning a cord circuit finder and a line finder. If there are several simultaneous calls, they are not handled at the same time, but consecutively. Such a method can be adopted only if high-speed selectors, such as the Philips uniselector U 45 A, are employed. The cord circuit finder and the line finder are then positioned so rapidly that the delay caused by the consecutive handling of simultaneous calls is negligible.

The positioning of the cord circuit finder and the line finder may be somewhat clarified with the aid of the simplified diagram of *fig. 7*. This shows the four contact banks of a line finder *LF* and the 8 contact banks of a cord circuit finder *CCtF*; a line circuit, a register and a cord circuit *CCt*, are, however, shown in simplified form.

As soon as the receiver of one of the extensions is removed, the line relay *L* (with three windings) is actuated by the closing of the cradle switch *cs* of the extension. When contact l_1 closes the relay *CD* (call detector) is actuated, as a result of which the register designated by the call distributor (the contacts *r* of this register being closed) attracts the relay *S* via cd_1. This causes the test circuit for the cord circuit finder (with test relay *T*) to be closed in the register by means of contact s_1. Also the release magnet *RM* of the cord circuit finder is actuated by the closing of contact s_2, after which this selector starts rotating. As a result of the closure of contact cd_2 all the free cord circuits (*CCt*) relating to the group of 100 lines to which the caller's extension belongs, are marked in arc *I* of the cord circuit finder, for the contact c_4 in the free cord circuits is closed, whereas this contact is open when the cord circuit is engaged. As soon as the brushes of the cord circuit finder touch the contacts of a free cord circuit, the high-speed test relay *T* is actuated, as a result of which the release magnet *RM* of the cord circuit finder releases by the opening of contact t_1; the finder then comes to a standstill. At the same time the closing of relay *T* causes the actuation of a relay *A* (not shown in the figure) having contacts a_1 and a_2. In this way the test relay *T* is connected into the test circuit for the line finder by way of contact a_1, after which *T* releases and t_1 closes again. Consequent on the tripping of contact a_2 the release magnet *RM* of the finder is actuated and the latter starts rotating. As soon as the brushes of the line finder are positioned on the contacts of the caller's line, the test relay is actuated again, in the circuit: earth, contact S_1, test relay *T*, contact a_1, contact bank *VI* of the cord circuit finder *CCtF*, contact bank *d* of the line finder *LF*, the closed contact l_2 of the line relay, contact co_1 of the relay *CO*, the connecting wire to the class-identification multiple, the class-identification wire, contact *r*, the class relay of the class to which the extension in question belongs (*TT* in this case), and the voltage source. Because the test relay is actuated, the release magnet of the line finder *LF* releases on account of the opening of t_1, as a result of which the line finder is stopped. Class relay *TT* is actuated, so that then the class to which the caller's extension belongs is fixed in the register. Even though the subscriber does not belong to the class *LT*, the class relay *LT* is nevertheless energized by the class relay that *does* close (in this case *TT*). Relay *R* releases on account of the opening of contact lt_1, so that the contacts *r* open as well. The register is then no longer connected to the class-identification multiple; nor can it be influenced by the call detector *CD* via relay *S*, if there is another call. As a consequence of the activation of the test relay, a relay *C* (not drawn) in the cord circuit *CCt* is actuated. If the contacts c_2 and c_3 are then tripped, the result will be that the *a* and the *b* wire of the calling station are connected to the register. The relay *co* is actuated by the closing of contact c_1. The opening of contact co_4 disengages the call detector for the next call. The connection between the line circuit and the class-identification multiple is broken by means of contact co_1, while by opening the contacts co_2 and co_3 the supply of the extension via the line relay *L* is broken.

After positioning of the line finder, the register gives the caller the dialling tone as a sign that the dialling may be started. Three digits will have to be selected, if a layout as shown in fig. 6 is involved. The number of dial impulses of every digit chosen by the caller is counted in the register with the aid of a relay counting circuit. After the counting of a digit the counting relays transfer the result to a group of storage relays, after which the counting relays return to their neutral position. There is no transfer, however, of the result of the dial impulses of the last digit; in this case the counting circuit also acts as a storage circuit.

After selection of all three digits the register starts positioning the selectors. For this purpose the register must use a common marker, of which there is only one for exchanges up to about 600 numbers.

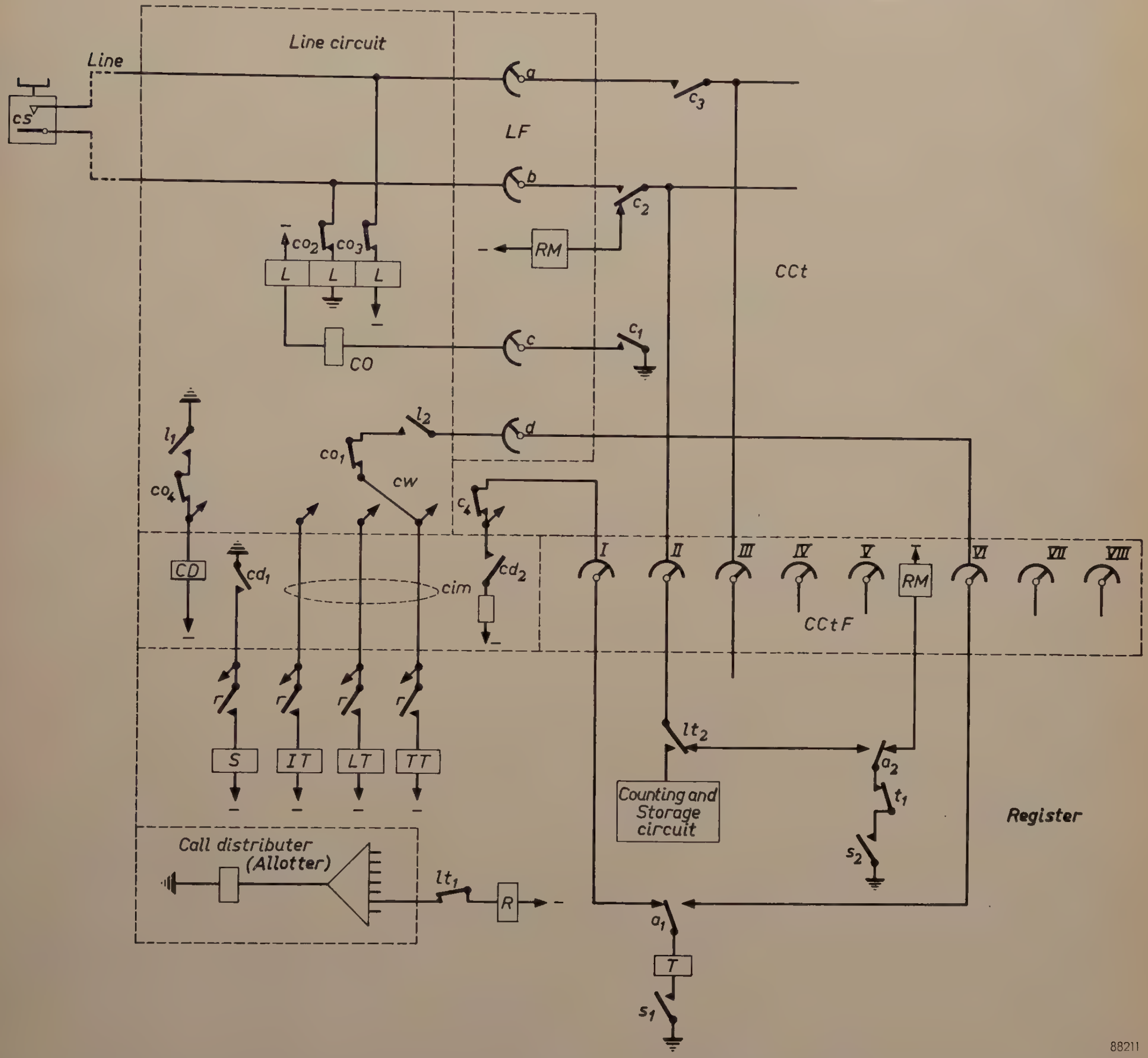

Fig. 7. Simplified diagram of the line finder, the register and the cord circuit. *LF* line finder with contact banks *a*, *b*, *c* and *d*; *CCt* cord circuit; *CCtF* cord circuit finder with contact banks *I*, *II*, etc., *cs* cradle switch of the telephone set; *CD*: call detector; *RM* release magnets of line finder *LF* and cord circuit finder *CCtF*; *L* line relay; *CO* cut-off relay; *IT*, *LT*, *TT*: class relay for internal, local and trunk calls respectively; *T* test relay. The relay contacts are indicated by the same letters (in lower case) as those used for the indication of the relays to which they belong — consequently, co_1 is a contact of relay *CO*; *cim* class-identification multiple; *cw* connection from the line circuit to the class-identification multiple. (The function of the contact banks, *IV*, *V*, *VII* and *VIII* of the cord circuit finder is not discussed here.)

As it is feasible to connect only one register to the marker at a time, there is also a common gate lock-out *GaLo* which ensures that the registers are admitted in groups and dealt with one by one, after which a new group is admitted.

As soon as the marker is disengaged, the register is connected to it, after which it transfers the dialling data obtained from the caller to the marker. The marker then marks the group of final selectors through which the desired number can be reached in the bank of the group selector and furthermore the line itself is marked in the bank of the final selector (via *3* and *5* respectively in fig. 6). The register consecutively positions the group selector and the final selector, after which the marker is disengaged and available for the next register.

In this case again, only one register out of a group is enabled to position a group selector - final selector combination. This method offers considerable advantages, as it makes it possible to introduce important simplifications into the circuits and the establishment of double connections, for example, is entirely prevented. This, again, is possible only by the use of the high-speed uniselector U 45A, for then the holding times of the marker are so short that the resulting delays are negligible.

It will be noted that in the entire exchange — if its capacity does not exceed approximately 600 numbers — there are never more than two selectors running at the same time, viz. one in the group selector - final selector category and one in the cord circuit finder - line finder category. As a result of this, the exchange is not only practically silent, but the severe mechanical vibration occurring when many selectors are running simultaneously are also avoided. In this way less electric noise voltages occur and, as a consequence, the system UB 49 is remarkably free from selector noise.

After the positioning of the group selector and the final selector it is checked via the register whether the selected line is engaged or disengaged. If the line to the called station is engaged, then the register breaks the entire connection. All circuits are cleared and the caller hears the engaged signal from his own line circuit. If the called station's line is disengaged, then the register only disengages itself, so as to be in a position to handle further calls. The called station now receives the first ringing current and the subsequent periodical rings from the cord circuit which also supplies the current for the microphones of both the called station and the caller's station.

The microphone current flows via a relay in the cord circuit called the guard relay. This current is interrupted when the microphone is put on the hook; the guard relay then releases, which initiates the process of clearing the connection.

Outgoing traffic via public lines

Usually the circuits of the system UB 49 are so designed that the lines to the local exchange are accessible when the caller dials one particular digit. These lines are connected to contacts in the banks of the group selector, and the register designated by the call distributor starts positioning it as soon as the pulses from the aforesaid single digit are received. When discussing internal connections it was mentioned that the register has determined the class to which the caller's extension belongs before the dialling tone is emitted. If he is not allowed to make outside calls, i.e. if his line relay is not connected to the relevant wire of the identification multiple, then the register does not start the group selector, but it breaks the entire connection built up so far and and the caller hears the engaged signal from his line circuit. If he is entitled to make local calls, then the register adjusts the group selector to a free public line circuit. Furthermore it applies a special signal to the cord circuit and disengages itself for the next call. The result of the special signal is that the supply in the cord circuit is not switched on and that the speech wires are connected from the line circuit to the public line circuit *PLCt* (fig. 6), from which the microphone is now fed via a guard relay in the public line circuit. The question whether the connection is broken or not, thus no longer depends on the cord circuit, but on the public line circuit.

The group selector is positioned to a free public line with the aid of the marker by means of a marking connection from the register to the contact bank of the group selector, via the marker and the free public line circuits. This connection also serves for passing the signals to the public line circuit in order to indicate whether or not the caller is entitled to make trunk line calls, a datum that is fixed in the register by the actuation of the relevant class relay (*IT*, *LT* or *TT*, see fig. 7). If the caller is not authorized, then this signal switches on a device in the public line circuit which prevents trunk calls from being made (*TTR*). The way in which such a device operates depends on the way in which trunk connections are established in a given country. We shall not enter further into this matter here.

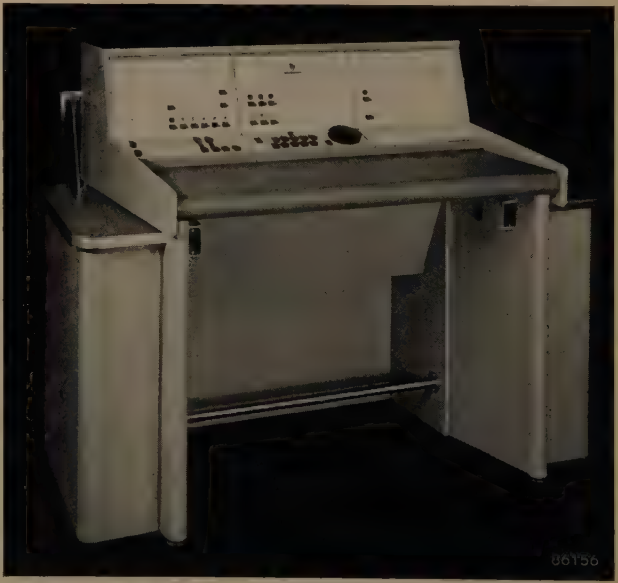

Fig. 8. Operators desk for handling the local traffic of a PABX type UB 49 with an arbitrary number of public lines.

The exchange UB 49 enables a caller who has built up an outgoing public line connection to consult with another person in the private system during this call. The way in which this is done will be discussed in the next section.

Incoming local calls

In the case of incoming calls on the public lines the operator's assistance is needed for the connection of these lines to the extensions. For this purpose use must be made of a control desk (*fig. 8*) or a control set (*fig. 9*). In principle both installations offer the same facilities. The (smaller) control set will mainly be used in those cases where the operator has not got a fulltime job; in such cases it is more economical to put the operators set on a normal desk at which the operator does her other work.

A new system is used for the standard version of desk and set, which will now be described. In this system the public lines no longer appear individually on the operator's desk. In order to estimate the new technique at its true value, it is necessary to consider the various possible situations which can arise during a call from outside.

a) The call has been received, but has not yet been answered.

b) The call has been answered, but has not yet been put through.

c) The desired person is not immediately available after being called. In this case the public line is switched to the waiting position and remains engaged while the operator handles other calls in the meantime.

d) If there is no reply from the extension called, the operator has to inform the caller of this fact.

e) If the called person's line is engaged, then the operator may interfere in the conversation and offer the outside call. If the called person does not wish to interrupt the conversation at once, then the operator has to try again after some time.

f) The called person answers and the conversation proceeds.

g) The called person requests the operator to transfer the call to another extension.

h) The called person may return call to the operator without any comment.

i) The caller may request to be consecutively connected to various extensions. In this case the operator must see to it, by carrying out a special switching operation, that the call is passed back to her desk, whenever the receiver of an extension is put down.

j) The operator must receive a special signal, if she has chosen an extension which may not receive local calls, or if she has carried out some incorrect manipulation.

When all the public lines are permanently connected with the operator's desk, it is not possible to fit more than two or three lamps per line for lack of room. One should then try to indicate the various situations mentioned above with the aid of lenses of different colours, lamps dimmed or full on, or with lamps that flicker at various frequencies. The picture of the lamp panel, however, soon becomes distracting in that case, while the signalling system still does not come up to standard.

For the above reasons another solution has been chosen. One lamp and an associated push button are now provided for each of the possible situations. The

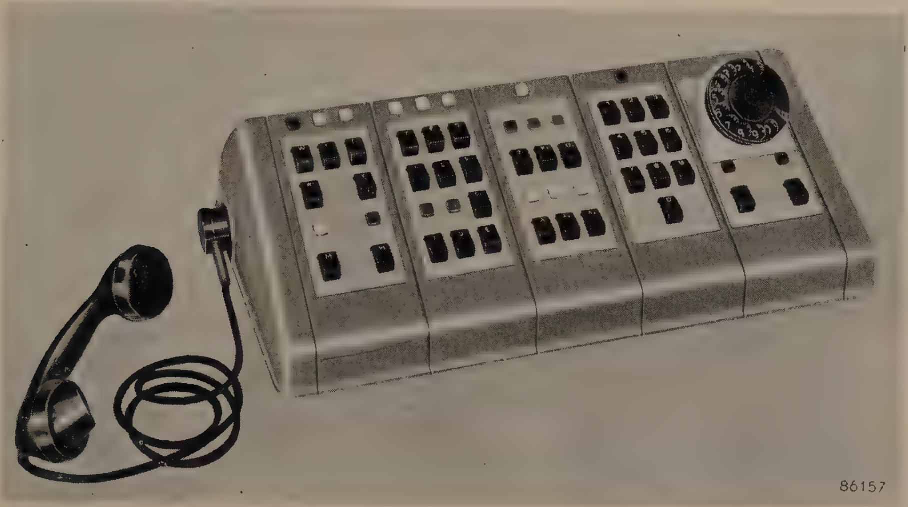

Fig. 9. Operator's set having the same function as the desk in fig. 8.

public lines are no longer in permanent connection with the operators desk. This connection is established only for one line at the moment at which the push button is operated and only the situation of that particular line is indicated on the desk. Moreover, there are lamps for showing that one or more connections to the public exchange are in one of the situations *a*, *b*, *c*, *d*, *e*, *g*, *h* or *i*, and that the operator must take some action. Another advantage of this system is that the design of the operators desk is independent of the number of public lines to be controlled. If there is too much local traffic for one operator, then two positions can simply be connected in parallel. The signal lamps for all the situations enumerated above, for which the operator's assistance is called in (*a*, *d*, *e*, *g*, *h* and *i*) are white. The waiting lamp is red, as the situation indicated in this way requires the operator's special attention. Green-coloured lamps indicate whether the operator's desk is connected to a public line or to an extension.

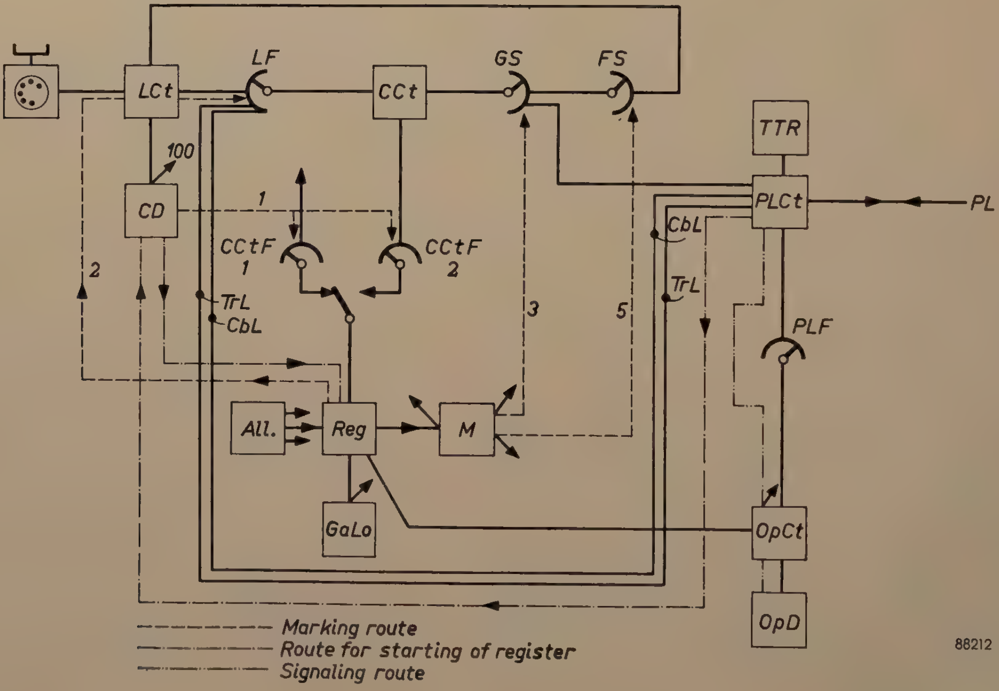

Fig. 10. Layout of a PABX type UB 49 for more than 100 extensions (see also fig. 6), with provisions for the operator and for call-back added to it. *PLF* public line finder, *OpCt* operator's position circuit, *OpD* operator's desk, *TrL* transfer line, *CbL* call-back line. For other letters see fig. 6.

We shall now give a brief description of the way in which an incoming local call is put through (*fig. 10*). If there is an incoming call on one of the public lines *PL*, a general calling lamp lights up on the operators desk *OpD*. If the operator depresses the appropriate button, the public line finder *PLF* of the corresponding operator's circuit *OpCt* is started, as a result of which she is connected to the caller's exchange line. Once the caller has told her to whom he wishes to speak, she depresses the button for internal interconnection and she is then connected to the transfer line of the public line circuit *PLCt*. By switching over to this transfer line (*TrL*), which is connected to the banks of the line finders as a normal line to an extension, the operator makes a normal call, so that a register is started. This register hunts for a free cord circuit and positions the latter's line finder to the transfer line. The operator is thus connected to a register in the same way as an extension and she receives the dialling tone from the register.

At the moment when the register positions the line finder to the transfer line (*TrL*) it is also ascertained that the call comes from an operator. The means by which this is done will not be discussed here, as this would carry us too far. As a consequence a direct connection is established via 4 wires between the operator's position circuit and the register. The four-wire connection enables the operator to store the digits in the register very rapidly by means of the push buttons on her desk. The connection is established within 0.5 sec after the button is depressed for the last digit, as high-speed selectors are incorporated.

In this case as well, the cord circuit is connected through while being controlled by the register. The latter then ascertains by means of a subsequent test whether or not the caller is entitled to receive local calls. If not, then the private connection is broken and a lamp on the desk warns the operator. If, however, the caller is authorized to receive local calls, then his extension is fed from the public line circuit. whence the call is made. In that case the operator may either remain in the circuit until the called person answers, or withdraw from it at once by depressing a button provided for the purpose. In the latter case the called person's station is automatically connected to the public line, if he answers the call. If he does not, however, the call is automatically passed back to the operator's desk after about 20 sec. If the called person's line is engaged, then the operator can enter into the circuit and offer the local call. By depressing a button provided for the purpose the operator can re-establish the connection with the calling subscriber in order to inform him of her findings.

Once the connection between the public line and the extension has been established, the called person using the extension may consult with another person using an extension without breaking the connection with the public line. In order to achieve this, the public line circuit is connected to the contact bank of the line finders by another line, the call-back line (*CbL*). As soon as the button for calling back on the extension is depressed, a call starting from the public line circuit is made by way of the call-back line. The public line is temporarily cut out, but retained in the public line circuit by means of an auxiliary circuit. At the same time the station connected to the transfer line is connected with a cord circuit and a register by way of the call-back line. As soon as the dialling tone is heard, the desired number is dialled, after which both extensions are connected in the usual way. If the button for call-back of the first extension is then depressed again, the connection via the call-back line is broken and the connection with the public line is re-established, If, however, the button for call-back of the second extension is depressed, then the connection between the public line circuit and the first extension — by way of the transfer line — is broken and the second extension is connected to the public line by the call-back line. This procedure can be repeated as often as desired; the transfer line and the call-back line then change their function alternately.

Overflow group selectors

Once the exchange has attained a certain size it is no longer possible to connect all final selectors and public lines to every group selector. In most cases the group selectors are then divided into two (or, in large exchanges, into more) parts, after which the final selectors of each group of a hundred extensions are uniformly distributed over these parts The consequence is, however, that the final selectors are accessible to a limited extent only. For, if a certain group selector is chosen, then only part of the final selectors in the hundred-group required are accessible. All these final selectors may be engaged, while it may be possible that the final selectors for that particular hundred-group which are connected to the group selector of the other part are still disengaged. In that case the efficiency of the final selectors and exchange lines drops [4]).

In an exchange with more than about 600 lines the system UB 49 obviates this disadvantage by using overflow group selectors. A certain number of the final selectors for every group of one hundred extensions (e.g. 7 or 8 out of 15) are directly connected to every group selector (*GS*, *fig. 11*).

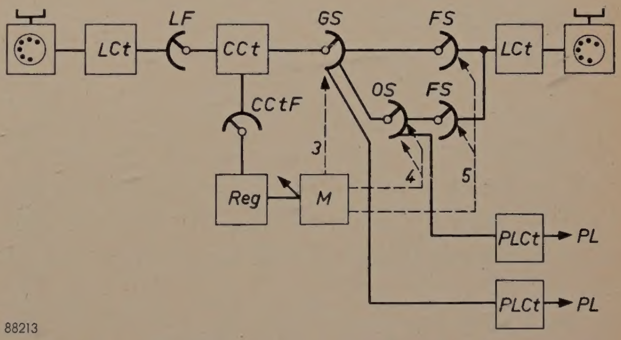

Fig. 11. Diagram of connections with overflow group selectors. *LCt* line circuit; *LF* line finder, *CCt* cord circuit; *GS* group selector; *OS* overflow group selector; *FS* final selector; *CCtF* cord circuit finder; *M* marker; *PLCt* public line circuit; *PL* public line.

The remaining final selectors are connected to the contacts of each of the overflow group selectors (*OS*). It is then checked for all calls whether the final selectors connected to the group selectors are disengaged. The portion of calls that cannot be handled by these final selectors is passed on to the overflow group selectors. These selectors thus receive the remaining calls from all groups of one hundred stations; the overflow group selectors still get a fairly large number of calls to deal with and consequently their efficiency is good.

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[4]) By the efficiency of, say, a group of lines we understand the ratio of the traffic (number of call-minutes per hour) that can be handled by this group with a certain grade of service, to the traffic that would occur if all lines were continuously engaged. The efficiency of a large group is higher than that of a small group, if the grade of service remains the same. This means that a group of, say, 100 lines can handle more traffic than two groups of 50 lines each, with the same grade of service.
See for example J. Atkinson, Telephony (footnote [2]).

The marking (via the lines *3* and *5*, if a direct connection can be established, and via the lines *3*, *4* and *5*, if the connection is established by way of an overflow group selector) is ensured by the marker circuit (*M*) in combination with the register. In the case of an indirect connection the marker circuit brings the register to the state required for the positioning of three selectors, viz. *GS*, *OS* and *FS*.

The local traffic is, in a similar way, offered to the public line circuits (*PLCi*) connected to the group selectors and then to the circuits connected to the overflow group selectors.

Networks

If various scattered private exchanges have to co-operate (external private traffic), a cable network must be laid between these exchanges. The system UB 49 can be adapted to any required network configuration. The use of a central marking device makes it possible to determine the most favourable route for every connection in this external traffic. The marking device also investigates whether the traffic can be passed to the other exchange directly, or — if all lines to this exchange are engaged — by way of a third exchange (overflow traffic). In mesh-shaped networks a considerable improvement of the efficiency of the groups can be achieved in this way.

Special provisions in the system UB 49

Although they do not belong to the normal equipment of the UB 49 exchange, all kinds of special devices can be fitted;

a) *Night traffic installation.* Normal equipment may control the public lines during the evening and night hours and on Sundays in the operator's absence. After a normal extension has answered a local call the desired extension may be called by way of the call-back line; this extension may then take over the call.

b) *Conference device.* A conference device enables a maximum number of 10 users of extensions to hold a telephonic conference, either together or in groups. The connections are controlled by the operator who first dials all the desired extensions, after which the bells of all these sets are rung simultaneously.

c) *Automatic staff location.* Persons who are wanted on the phone can be warned by means of acoustic and optical signals. The device in question is switched on by dialling a call number, which causes signals to be automatically given according to a fixed code. As soon as the called person dials a certain number (the report-number) on an arbitrary extension, he is automatically connected to the caller's extension.

The provision of all these facilities presents no special difficulties and need not be described further here.

Summary. After an introduction dealing with the general development of private telephone exchanges, a description is given of the UB 49 exchange. This operates on the register system in which the characteristic disadvantage (slower action) of register systems is overcome by the use of a high-speed uniselector, the Philips U 45 A. The characteristic advantages, (reduction of equipment in large exchanges), however, are retained, while many additional advantages are obtained. For instance, the system requires a minimum of maintenance and it is remarkably free from selector noise.

A special operator's desk has been developed for the establishment of incoming calls. The special feature is that the public lines are not permanently connected to the desk; they are connected to it only at the moment when control is required. This renders the design of the desk independent of the number of public lines to be controlled. In addition much more complete signalling of the various situations applying to the public lines is possible. The introduction of selection by means of push-buttons makes it possible to pass on local calls to extensions very quickly.

ABSTRACTS OF RECENT SCIENTIFIC PUPLICATIONS BY THE STAFF OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to Philips Electrical Ltd., Century House, Shaftesbury Avenue, London W.C. 2.

2269: S. Duinker: A shifting register using ferro-resonant flip-flops (Appl. sci. Res. **B4**, 317-328, 1955, No. 5).

Ferro-resonant effects, i.e. instabilities occurring in the steady state response of non-linear circuits by gradual variation of some circuit parameter are briefly discussed and the application of these effects in trigger and flip-flop circuits is pointed out. A shifting register using ferro-resonant flip-flops is described in which the information is shifted by unindirectional pulses. By simple means it is possible to shift the information in both directions depending upon the polarity of the shifting pulses. Some details of an experimental register for a telex-on-radio system working at a supply frequency of 20 kc/s and permitting shifting pulses at a repetition rate of 0.8 kc/s are discussed. Attention is paid to the design considerations especially for the application of supply frequencies in the Mc/s range.

2270: J. J. Opstelten and N. Warmoltz: A double-sided micromanometer (Appl. sci. Res. **B4**, 329-336, 1955, No. 5).

A condenser plate is mounted close to each side of a thin diaphragm, separating two chambers. The two capacities thus formed are part of a bridge circuit which is fed by a high frequency oscillator. An amplifier with a narrow bandwidth, a rectifier and a micro-ammeter are used as a null-indicator. At one side of the diaphragm a pressure prevails, much lower than the pressure to be measured; at the other side the gas is admitted the pressure of which is to be measured. The displacement of the membrane by the gas pressure is compensated electrostatically by the aid of a calibrated potentiometer. The reading of this potentiometer is a linear measure for the pressure as a result of the differential way of compensating. The range is from 10^{-5} mm — 1 mm of mercury pressure difference at any absolute value. The apparatus is made of chemically fairly resistant materials, and its indication is independent of the nature of the gas, so that it can be used for almost every gas.

2271: J. Bloem and F. A. Kröger: A relation between hardness and stoichiometry in lead sulphide single crystals (Nature **175**, 861-862, 1955).

Single crystals of PbS were prepared and reheated under various sulphur pressures at 1200 °K to control the stoichiometric composition. After rapid cooling of each crystal to room temperature, the concentration of free charge carriers (electrons or holes) and the hardness were determined. It was shown that stoichiometric crystals contained the lowest carrier concentrations. Reheated at higher sulphur pressures, an excess of sulphur (consistent with lead ion vacancies) was introduced together with positive holes. At low sulphur pressures sulphur ion vacancies together with free electrons were present. These concentrations vary from about $10^{-3}\%$ to $10^{-1}\%$ when reheated under various sulphur pressures. The hardness of the crystals also showed a minimum value for stoichiometric crystals; for strong *n* and *p* type crystals the highest values were observed.

2272: W. J. M. Vestjens: Een mannetje van Dixippus morosus Br. (Entomologische Berichten **15**, 404-406, 1955). (A male of Dixippus morosus Br; in Dutch).

Dixippus morosus has been bred since 1950, and from 1952 onwards, on a larger scale in cages about 20 × 20 × 25″. In August 1954 a male occurred. It is distinguished by its smaller size, by a red stripe at the ventral side between coxae I and II, and by the lack of the red marking at the inner side of the anterior femurs.

2273: L. A. A. Sluyterman: Molecular weigth of insulin as derived from paper electrophoresis (Biochim. et Biophysica Acta **17**, 169-176, 1955).

Some uncertainty exists as to whether the molecular weight of insulin is 6000 or 12000. The experiments described in this paper may help to decide this question. Samples of insulin were treated with various amounts of acetic anhydride under conditions favourable for specific acetylation of the amino groups. Thus products with various contents of free amino groups were obtained. Paper electrophoresis of these products demonstrated the progress of the acetylation reaction by the successive appearance of new bands and the disappearance of the initial insuline band. A total number of three new bands were found. This shows that acetylation of insulin occurs in three steps, which suggests the presence of three amino groups in one molecule of insulin. According to chemical analysis insulin contains three amino groups in each unit of molecular weight 6000 (Sanger, 1945). Hence the present experiments indicate that the molecular weight of insulin is 6000.

2274: J. H. Stuy: Photoreactivation of ultraviolet-inactivated bacilli (Biochim. et Biophysica Acta **17**, 206-211, 1955).

The phenomenon of photoreactivation has been studied with three cultures of bacilli. It has been shown that they could be reactivated by light with wavelengths of 3655, 4047 or 4358 Å after ultraviolet inactivation. Since these radiations also have an inactivating effect, the photoreactivation may be small, even not noticeable, when the dose-rate of the incident light is too great. Bacterial spores did not show photoreactivation.

2275: E. W. van Heuven: On the noise of fluorescent lighting installations (Acustica **5**, 101-111, 1955).

In the frequency spectrum of the noise of a fluorescent lamp ballast, "hum" and "rustle" can be distinguished. Hum comprises small even multiples of the mains frequency, at which the dimensions of the ballast are small in comparison with the wavelength of the sound in the air. The noise at these frequencies is, therefore, mainly produced by the ballast acting as a vibration exciter to larger mounting surfaces. Rustle frequencies (about 1000—3000 c/s) are radiated directly by the ballast itself. Hum may be eliminated by use of a core construction where the displacements due to magnetic attraction across the air-gap cancel out the magnetostrictive displacements at the mounting points of the reactor. Rustle radiation must be isolated by putting the ballast in a closed box. A filling for the empty space in these boxes providing acoustical impact sound insulation and good thermal conductivity is described.

2276: J. Bloem, F. A. Kröger and H. J. Vink: The physical chemistry of lead sulphide in relation to its semiconducting properties (Rep. Bristol Conf. Defects in Crystalline Solids, 1954, Phys. Soc. London 1955, p. 273).

The semiconducting properties of lead sulphide single crystals have been measured after heating at various temperatures in controlled atmospheres. Thermoelectric power measurements indicate an energy gap of 0.3 eV at room temperature, and an effective electron and hole mass of about 0.25 of the electron mass in free space. With the use of the theory of Kröger, Vink and van den Boomgaard it was possible to deduce the width of the energy gap and the position of the various vacancy levels as a function of temperature, from 800 to 1200 °K.

2277: F. van der Maesen and J. A. Brenkman: On the behaviour of rapidly diffusing acceptors in germanium (J. Electrochem. Soc. **102**, 229-234, 1955, No. 5).

The acceptor activity of Cu and Ni and their diffusion in germanium have been investigated. Their action as acceptors as well as recombination centres gives reason to believe that impurity atoms are placed substitutionally in the lattice. However, the value of 10^{-5} cm^2/sec of the diffusion constant makes it likely that the diffusion goes interstitially. This leads to the concept of an equilibrium existing between substitutional and interstitial atoms. The fact that the diffusivity is dependent on the range of diffusion can be explained qualitatively on the basis of the picture given above,

2278: H. C. Hamaker: De betekenis van de statistiek voor de ontwikkeling van de experimentele wetenschap (Sigma, **1**, 55-58, 1955, No. 3). (The significance of statistics in the development of experimental research; in Dutch).

The application of statistics to technical problems is shown to be a basically new phase in the development of technology.

2279: F. K. Lotgering: Order-disorder phenomena in iron sulphides $Fe_{1-\delta}S$ (Z. Phys. Chemie **4**, 238-241, 1955 No. 3-4).

Iron and sulphur form a continuous series of compounds with compositions varying from FeS to Fe_7S_8. The sulphides with a low sulphur content are antiferromagnetic, those with a high sulphur content are ferromagnetic while an anomalous ferromagnetic behaviour appears at compositions between these two regions. The magnetic and crystallographic properties are experimentally investigated and explained using the simple theory of order-disorder phenomena.

2280: T. Holmes: Something new in sodium lamps (Public Lighting **20**, 662-664, 1955).

Description of a sodium lamp constructed of a glass with improved resistance to sodium vapour. The use of this glass is made feasible by employing a xenon-neon mixture in place of the argon-neon filling commonly used in the past to reduce the ignition voltage.